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Contents

Whisky and Water: the Essence of Scotland 1
Dr Stephen Cribb, Author, Broadcaster and OU Tutor

Geology on the Scottish side of Iapetus: links with Greenland, Scandinavia and North America 4
Dr Cornelius Gillen, University of Edinburgh

New finds in the Hopeman Sandstone 10
Carol Hopkins, Open University Earth Sciences Undergraduate

The Elgin Marvel 16
Dr Neil Clark, Hunterian Museum, Glasgow

The Aftermath of the Groningen Gas Discovery: 19
History of North Sea Exploration 1964-1999 in 30 minutes
Dr K W Glennie, University of Aberdeen

The Aberdeenshire Gabbros. a tale of two plutons 29
Sue Hay, OU Graduate and PhD Student, University of London

Palaeoecology of Old Red Sandstone Fish Beds of Scotland 37
Dr Nigel Trewin, University of Aberdeen

A Caledonian Scottish Assembly: 41
Dr Phil Stone, BGS Edinburgh

Book reviews 9, 15, 18, 28, 36, 40, 45, 46

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Cover illustration

Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
Bladed barite (white) Mag 580; ppl.	Botryoidal barite Mag 538; xpl	Spherulitic barite Mag 584; xpl.
Fasicular-optic barite Mag 549; xpl.	Banded barite Mag 538; xpl.	Banded barite Mag 538; ppl.

Whisky & Water – the Essence of Scotland

Dr Stephen Cribb, Geologist, Author and Broadcaster

Firstly I would like to thank OUGS for inviting me. I have been associated with the Society for a very long time. Nearly twenty years ago I led and attended London Branch trips, I have done a trip for East Midlands and have another next Easter and now that I live in the far north of Scotland I am a member of the West of Scotland Group. Despite what I have just said about my connections with OUGS, I have never been to a Symposium before, so I have assumed that it is something like Summer School.

My original interest in the geology of brewing and distilling came when I was an S238 tutor. Whilst demonstrating at the Nottingham Summer Schools it was easy to show people how aggregates were produced from the original quarry source, but not as easy to make water interesting. The detail of this talk is the result of that attempt and has also given rise to the book Whisky On the Rocks – origins of the 'Water of Life" (Cribb S & Cribb J, 1998, BGS, 72pp) which my wife and I recently published.

To continue the Summer School metaphor I guess that this talk should be something like a tutorial. So, is it to be remedial or enrichment? Looking at the delegate list I feel sure it has to be remedial!

Researching and writing the book itself was quite fun. Commissioned by BGS the original name was to be Scotch on the Rocks but we were beaten to that title by Lord (Douglas) Hurd who used the title for a reputedly racy novel. We also had an interesting battle with the previous BGS director Peter Cook, an Australian, who was very unwilling to allow me to include the Northern Irish whisky Bushmills as he said it was Irish and thus unfair to Scotland to mention it.

Whisky-making is essentially a brewing process followed by distillation of the brew. The first stage is called Malting. This is where barley is sprinkled with water and allowed to germinate. This starts off enzyme processes which break down the starch in the grain to sugar. After a few days this process is halted by heating the barley and allowing a certain amount of peat smoke to pass through the barley. The second stage is called Mashing. The malted barley is ground and mixed with hot water during which time the sugar and other substances are extracted from the grain. The resulting liquid is then cooled and left to ferment using a mixture of brewing and wine yeasts which results in a beer-like liquid with an alcohol content of about 7%. The liquid then goes into onion-shaped copper stills where it is heated and the vapours that are produced pass up and over the top of the still into a condenser. The distillation process is normally repeated to produce a spirit of about 65% alcohol content. The raw whisky is then put into oak barrels and left to mature for at least the legal minimum of three years; though single malt whiskies remain in the barrel for much longer, commonly between 10-25 years depending on the distillery.

In the manufacturing process there are four crucial factors and it is the variability of the dominance of each of these factors which makes each malt whisky unique.

The degree of peating of the malt
As the barley is being malted a certain amount of peat smoke is allowed to pass through the grain. This peat reek is absorbed by the malted barley and the flavour imparted ranges from almost nothing to quite strong.

The shape and type of the still
The height of a still controls the amount of aromatics that pass into the final distillate. Tall stills produce a lighter cleaner spirit whereas smaller dumpy stills allow a lot more of the heavy aromatics to pass through.

The type of barrels
Traditionally these are used sherry barrels from Spain but Bourbon barrels from America are also used. These provide the colour to the whisky as well as influencing the maturation process.

The process waters
This is the water that is used for the mashing process and is the subject in which I am particularly interested. It has been known for a very long time that in the brewing of beer the differing chemical content of the process waters exert a significant effect on the type of beer that can be brewed. It is exactly the same brewing process in whisky, just a lot more subtle.

I would like to read you the first two lines from a poem called 'A Glass of Water' by May Sarton. I first saw this in London as one of the *Poems on the Underground* series and it sums up my interest in the subject:

"Here is a glass of water from my well.
It tastes of rock and roots and earth and rain".

This is the key to the production of different whiskies and it is this area in which the geology of the water sources becomes relevant.

The knowledge of the effects of water chemistry within the industry is surprisingly poor. If you ever visit the premier research department of distilling and brewing in this country, the Institute of Distilling and Brewing at Heriot Watt University, you will find library shelves full of books and papers describing different types of wood, different designs of stills, the effects of copper and theses on fermentation, but you will find virtually nothing on the subject of water and water chemistry. My book is, to date, the most scientific text that has ever been published concerning the role that water plays in distilling!

Distillers are often reluctant to talk about the chemistry of their process waters. Some are happy to say that the water source has no effect at all. Yet they jealously guard their unique source and, if asked to change, always reply "impossible". There is a mystique, which is not clearly understood. Even their knowledge of geology is amazingly thin at times, and this is often the same for whisky writers. I have seen in an authoritative whisky book 'the Highland Boundary Fault is an imaginary line between Stonehaven and the Clyde'. Imaginary? Rubbish! It is all very real. You can see it and you can walk along it if you wanted to – there's nothing imaginary about it at all!

Tradition in the industry states that the best water for distillation is 'soft water through peat over granite'. That seems fine, but in the current 100-110 malt whisky distilleries operating in this

country only around 20 use water of that description. The geology of Scotland is remarkably variable and therefore in reality so are the rocks from which the waters flow. Any geologist recognises that there will be a significant difference in the chemistry of waters sourced from granite, sandstone, schist or quartzite. However, when I talk to people at distilleries they are often oblivious to this fact.

In the simplest terms, if rainwater falls on igneous rocks like granite very little is absorbed. The water runs rapidly down slope under a cover of peat until it reaches an impermeable layer, such as glacial deposits in a valley bottom, where the water re-emerges as a spring. It has very little time to develop a mineral content and is therefore what we call 'soft'. This is most certainly not the case with water from permeable sandstones particularly, for our purposes, the Old Red Sandstone. The sandstones from ORS are permeable and have calcium carbonate cements, some of which dissolve producing groundwaters which are notably 'hard'. Both hard water and soft water contribute to the production of the wide range of malt whiskies.

Distilleries come in all shapes and sizes; they are situated on the coast, in valleys, on the tops of hills and on islands. They use water from boreholes, from rivers, from springs and lochans and every single water is unique in terms of its chemical analysis; not just in its main mineral analysis, but also in its trace element analysis, and it is this latter that is thought to be the main factor which affects the type of whisky distilled.

Whisky is probably the greenest drink of all – it is an eco-drink. When you have a dram you are drinking just a distillation of fermented barley and water. Not that I want to encourage you to drink - even a teetotaller could use the methods I will suggest. You can think of whisky as an aide memoire for the geology of Scotland as the water and whisky differ wherever you choose to visit.

My interest started when I looked at the Speyside malts and found that, based on tasting notes, they could be placed into three separate groups. I looked at the water sources and discovered that the three groups corresponded very closely with three different water sources. One group took its water from the granite mass to the west of Dufftown which forms Ben Rinnes and the Conval Hills. A second group took water from the well-bedded, light-grey Dalradian quartzites of the Grampian Group; and all but one distillery produced very similar whiskies (the exception being Macallan which uses only Oloroso sherry barrels, where the sherry effect overrides everything else). The third group took their water from a wide range of Dalradian quartzites, phyllites and schists and produced a further distinctive group of whiskies. I was convinced by these findings but, in the usual words of a consultant, decided that much more research was necessary.

Right in the middle of Speyside is Dufftown, surrounded by seven major distilleries, Glenfiddich, Balvenie, Mortlach, Glendullan, Dufftown, Convalmore and Pittyvaich. Indeed there is a saying: "Rome was built on seven hills – Dufftown built on seven stills." But there is an eighth distillery. One of my favourite buildings built with very attractive dark stone and blue paintwork. This is Parkmore which closed in 1926 having experienced problems with their process water. Whereas the other seven distilleries take their water from the granite to the west of Dufftown, Parkmore used water from the limestone on the east side of the valley and the high calcium carbonate content caused the problems. This has happened elsewhere. If we go to the north coast west of Port Soy there is a distillery called Glenglassaugh which has struggled on for years with water problems, and at one time even tried importing water from elsewhere. To we geologists the reason for the problems is obvious. The water source lies inland in a narrow valley behind the distillery which is formed from a limestone similar to that in the Dufftown area.

Let us go further afield. Between the Highland Boundary Fault and the Great Glen Fault is an area called the Grampian Highlands. This stretches from the islands of Islay and Jura in the south west to the Buchan coast in the north east. Within this area there are many igneous intrusions of granite, basic and ultrabasic composition. The mountain of Lochnagar provides water for the Royal Lochnagar distillery which is situated behind Balmoral Castle. At Knock hill, east of Keith, the water seeps out between the Dalradian schists forming the top of the hill and the gabbro beneath it. The whisky produced has the gaelicised name of Cnoc. Further south, around Insch, seventeen individual springs provide the water source for Ardmore, a very unusual whisky, again with an ultrabasic water source.

An excellent trip (with someone else driving) is to undertake the south to north traverse between the Highland Boundary Fault and the Great Glen Fault, following the A9 from Perth to Inverness, taking in the five distilleries on the way. We start off at Perth on the rich agricultural land underlain by Old Red Sandstone. At Dunkeld the Highland Boundary Fault is crossed and suddenly the mountains appear. Our first distillery is Blair Atholl at Pitlochry and two miles to the east is the small distillery of Edradour which takes its water from high in the hills around Ben Vrackie. Continuing north, up the pass of Drumochter, it is not long before we reach the highest distillery in Scotland, Dalwhinnie. Starting the descent we eventually pass the town of Newtonmore, near to which is the distillery Drumguish, a malt whisky that has only recently appeared on the market. Further on still, near to Carrbridge is the huge distillery of Tomatin which takes its water from the Allt na Frith, one of the most romantic of water sources in a rocky valley full of junipers. The A9 continues northwards for another 30 miles until suddenly it drops steeply to Inverness, the Moray Firth and the Great Glen Fault.

Let us now go to the far south west, to the Argyll islands of Islay and Jura. Many people know the heavily peated malt whiskies of the south coast of Islay: Laphroaig, Lagavulin and Ardbeg, but there is a lot more to Islay than that. In the north east of the island is Caol Ila, close to outcrops of the fascinating Port Askaig Boulderbed. Even further north is Bunnahabhain, the only distillery on the island which takes its water from underground springs in dolomite. The resulting hard water has between 200-300ppm of calcium-magnesian carbonates. They use totally unpeated malt as well and consequently this whisky is very different to the others on Islay. Just along the coast from the distillery are huge stromatolite mounds. Here on the north east coast of Islay you can sip two very different types of dram and study two particularly important Dalradian rock types.

In the far west of Islay are the Rinns and the distillery of Bruichladdich, the most westerly of all distilleries taking its water from the dark-brown sandstones of the Colonsay Group, the affinities of which are still not understood. Are they related to the Dalradian or are they much earlier?

Let us go back to the north east, to the Moray and Buchan coast. Standing on the coast and looking north, on a good day it is possible to see the mountains of Sutherland on the other side of the Moray Firth. Beyond that is Caithness and with the eye of faith (which all geologists should possess) you could even see the Orkney islands. What I find so amazing is that had you stood in the same spot around 400 million years ago, not only would you have been on your own but it would have been very much hotter and drier, with large mountains to the north-east and the west and where today there is the North Sea there would have been a desert plain. In front of you on the plain would have been a basin into which material from the mountains was accumulating. In the near distance there would have been a red sand desert and further north a shallow lake containing armoured fish. We are of course in the middle of the Devonian and we are viewing the deposition of the Old Red Sandstone.

What I have just described is the outcrop of the Old Red Sandstone which runs east-west along the north-east coast and up through the Black Isle north of Inverness to Caithness and the Orkney islands. These rocks produce hard waters which are nothing like the soft waters used in Speyside or the other Dalradian areas. In the ORS areas the distilleries like Glenmorangie swear by their hard water and claim that it is this that has a significant effect upon the nature of the whisky that they make. The red sandstones can create problems as well because they form excellent farm land, and where there is intensive agriculture there is often a problem with high nitrate content in ground waters. Several distilleries in this area have closed particularly because of water problems.

A necessity to change a water source can present a very real problem to distillers. If you are a brewer and you make a really poor brew you know within a few days and can change what you are doing. Whisky, on the other hand, involves lead times of ten years or more, and as a distiller you might have to rely on the judgement of experts as to what the finished product will taste like.

A distillery near Elgin which has always used soft water recently had a problem with its supply and called upon consultants to find a new water source. They had no problem in finding water – all it needed was a borehole into the Old Red Sandstone. The problem was that the water was hard. The distillery now has a major decision to make. Should they risk the change from soft to hard water because, once made, it may be ten or more years before it is known whether the decision was correct.

In the far north are the flagstones of Caithness and the town of Wick where Old Pulteney is produced. Across the sea to Orkney we reach the two most northerly distilleries: Highland Park and Scapa. Both extract hard water from the sandstones.

We must now travel far to the south across the Highland Boundary Fault and into the Midland Valley. In the area of Old Red Sandstones there are similar water source problems to those encountered further north: microbiological and nitrate pollution. Many closures have occurred in this area.

The distilleries in the Midland Valley can be divided into two groups: those that take their water from the highlands but are situated in the lowlands, such as Fettercairn and Glenturret; and those with water sources specifically in the Midland Valley. Auchentoshan on the Clyde takes water from Carboniferous volcanic rocks, Glengoyne further north takes water from Devonian volcanics, and Glenkinchie, just south of Edinburgh, is the only distillery to take water from south of the Southern Uplands Fault from a reservoir in Ordovician volcanics.

The Tertiary volcanics are geologically the youngest group from which distillery process waters are sourced. These plateau basalts occur in Skye (Talisker), on Mull (Tobermory) and form the plains of Antrim (Bushmills). For completeness we should note that there is another Tertiary malt, the first single malt to be produced in southern Ireland for a very long time. Tyrconnell is distilled in the village of Cooley, near to the border town of Dundalk.

Sadly, several important malts have been lost in recent years. One is Bladnoch on the Wigtonshire coast, even further south than the distillery at Bushmills; there is also Tullibardine at the town of Blackford, north of Stirling. Blackford is also the home of two famous mineral waters: Gleneagles Mineral Water and Highland Spring, the latter being interesting in that it is neither in the Highlands nor does it come from a spring!

Many distilleries are not permanently shut – they are mothballed and can be re-opened when the economic situation is more favourable. Very rarely a brand new distillery is opened. The one everybody is waiting for is Isle of Arran at Lochranza, where the first 10-year Isle of Arran Malt, taking granite waters from the Eason Borach becomes available in 2001.

To finish my tour of Scotland I would like to read a few verses from a poem that I found by George Outram. The poem is called Drinkin' Drams.

He ance was holy
An' melancholy,
Till he found the folly
O singin' psalms;
He's now red's a rose,
And there's pimples on his nose,
And in size it daily grows
By drinkin' drams.

He ance was weak,
An couldnae eat a steak
Wi' out getting sick
An' takin' qualms;
But now he can eat
O ony kind o meat,
For he's got an appeteet
By drinkin' drams.

He studied mathematics,
Logic, ethics, hydrostatics
Till he needed diuretics,
To lowse his dams;
But now, wi'out a lee,
He could mak' anither sea,
For he's left philosophy,
An' taen to drams.

He found that learnin', fame,
Gas, philanthropy and steam,
Logic, loyalty, gude name,
Were a' mere shams;
That the source o joy below,
An' the antidote to woe,
And the only proper go,
Was drinking drams.

Geology on the Scottish side of Iapetus: links with Greenland, Scandinavia and North America

Dr Cornelius Gillen, The University of Edinburgh

Abstract

This paper reviews the geology of the Scottish Highlands: the Lewisian Gneiss Complex and the Torridonian, Moine and Dalradian Supergroups, and examines possible links with North America, Greenland and Scandinavia during the enormous time span prior to the closure of the Iapetus Ocean. Crustal structure, composition, age, evolution, metamorphism, cooling histories, igneous and tectonic events are outlined for the period 3300 Ma to 400 Ma ago, with most emphasis placed on the geology of the pre-Caledonian basement consisting of Lewisian Gneiss Complex, Torridonian succession and lower Palaeozoic marine shelf sediments in the Northwest Highlands and Outer Hebrides of Scotland.

Introduction

The North-west Highlands of Scotland lie to the west of the Moine Thrust Zone, which represents the margin of the Caledonian mountain belt. East of this zone are the Moine rocks of the Northern and Grampian Highlands, and south of the Great Glen Fault lie the Dalradian rocks of Argyllshire and the Southern Highlands. These belts of schist represent marine sediments that were folded, metamorphosed, intruded by granites, faulted and thrust in a north-westerly direction over the stable, ancient basement that constitutes the "foreland" to the Caledonian fold belt. On the foreland we find a crustal block – a small segment of the extensive North Atlantic craton – consisting of Archaean gneisses (the Lewisian) unconformably overlain by thick continental arkosic sandstones (the Torridonian), in turn overlapped also unconformably by a thin marine shelf succession of sandstones and limestones of Cambrian to Ordovician age, showing no regional metamorphic effects. Prior to the closure of the Iapetus Ocean, Scotland formed part of Laurentia, a continental region of crust including the Canadian, Greenland and Baltic Shields. The Scottish part of this supercontinent became detached during the opening of the present North Atlantic Ocean. It is separated from the Baltic Shield in Scandinavia by the Caledonian fold belt and by a series of grabens and sedimentary basins that range in age from Devonian to Mesozoic (in the North Sea).

The Lewisian Gneiss Complex

Figure 1. Lewisian Gneiss with rotated ultramafic pod; near Lochinver.

Europe's oldest rocks occur as a small fragment of craton in the Outer Hebrides and North-west Highlands of Scotland. The Lewisian rocks that form this segment are intensely folded gneisses, metamorphosed to granulite and amphibolite facies and intruded by basic dykes, granite sheets and quartzo-feldspathic migmatites and pegmatites (Table 1). As in other parts of Laurentia, the Lewisian is composed of tonalite–trondhjemite–granodiorite (TTG) gneisses with rounded enclaves of ultramafic rocks (hornblendite and pyroxenite), Figure 1, disrupted mafic–ultramafic layered igneous bodies (peridotite, dunite, gabbro, anorthosite) and minor metasediments (quartzite, garnet-kyanite schist, marble). This rock sequence may represent ocean

Table 1. A simplified chronology of Lewisian events

Sequence	Age, Ma	Event
1. Scourian (Central Belt) *Archaean*	2960–3030	Formation of tonalite–trondhjemite–granodiorite (TTG) gneisses, supracrustal sediments & ultramafic rocks; deformation, flattening and disruption of ultramafics; thrusting, banding
2. Badcallian (Central Belt)	2700	Granulite-facies regional metamorphism
3.	2200–2400	Scourie dyke swarm emplaced
4. *Proterozoic*	2000	Loch Maree sediments and lavas; crustal extension
5. Laxfordian	1900	Deformation & amphibolite-facies regional metamorphism
6.		Tectonic juxtaposition of Northern and Central Belts along Laxford shear zone
7. Laxfordian	1750	Migmatization; granite sheets and pegmatites intruded along shear zones

floor material that was subducted at a shallow angle, resulting in partial melting and crustal thickening by underplating and thrusting with associated granulite-facies metamorphism and depletion of the crust in the heat-producing elements K, Rb, Th and U. It should be pointed out that low concentrations of these elements may result not from granulite facies metamorphism, but may represent a primary feature of the original parent rocks which gave rise to the TTG gneisses, and depletion could have resulted via water-rich fluids being removed prior to partial melting at >18 kbar and 800ºC (Rollinson in Brewer 1996).

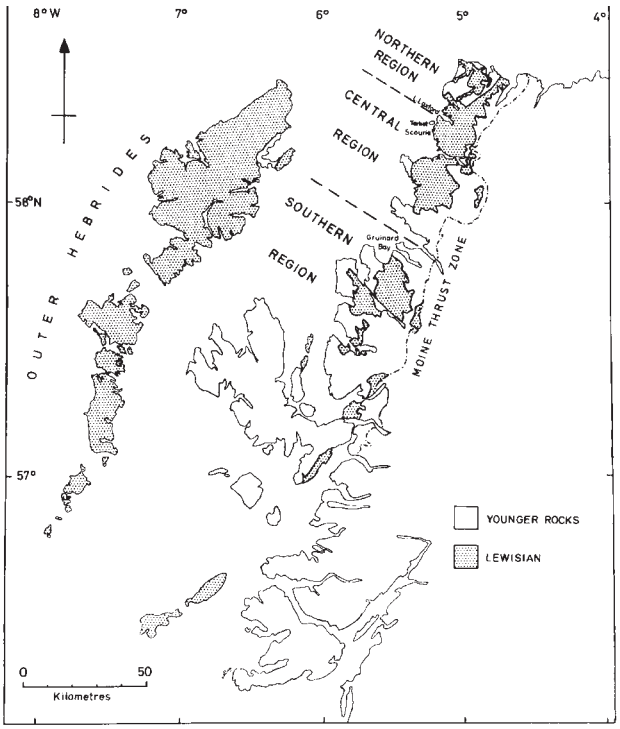

Figure 2. Lewisian Gneiss of Scotland showing regions of the mainland outcrop.

In Scotland the Lewisian is divided into three regions (Figure 2) – a central belt of mainly flat-lying banded granulites (Figure 3) flanked by northern and southern belts of migmatites, quartzo-

Figure 3. Banded granulite with minor folds; Scourie.

Figure 4. Granite sheets and pegmatite boudins in migmatite complex; Loch Laxford.

feldspathic gneisses and hornblende schists, deformed into steep folds and metamorphosed to amphibolite facies (Figure 4). At the boundaries of these belts are steep narrow shear zones into which granite sheets and pegmatites have been intruded. Each region has different bulk chemical composition, and it is possible that they formed at different crustal levels and locations and were brought together (or tectonically juxtaposed) by movements along the shear zones, which would then represent deep-level faults. An important component of the Lewisian is the Scourie dyke swarm of NW-SE dolerites, intruded around 2200 Ma ago and later deformed by shearing at their margins, and metamorphism to amphibolites (Figure 5).

Figure 5. Basic dyke in shear zone; Scourie.

In a regional sense, the Lewisian is part of an early Proterozoic (or Palaeoproterozoic, 1600–2500 Ma) belt in the North Atlantic region linking Scotland with Greenland, Labrador, Rockall and Scandinavia – i.e. eastern Laurentia and Baltica – where the Lewisian complex shares many common features in terms of rock types, deformational and metamorphic histories (Table 2). There are many similarities between the Lewisian and the Nagssugtoqidian in Greenland. As far as the Ketilidian is concerned, the best correlation is with the gneisses of Islay and Colonsay in the Inner Hebrides, which were previously considered to be Lewisian rocks (Gibbons and Harris 1994; Park and Tarney 1987).

Torridonian

The Torridonian is an assemblage of undeformed continental sediments, mostly thick cross-stratified redbeds formed in rifted

Table 2 Correlation of main events in the North Atlantic craton

Age, Ga	Scotland	North America	Greenland	Scandinavia
1.5–1.7	Laxfordian	Churchill	Nagssugtoqidian	Svecokarelian
1.8–1.9	Rhinnian	Makkovik	Ketilidian	Svecofennian
3.0–3.3	Scourian	Superior	E. Greenland craton	Karelian craton

basins, lying unconformably on the Lewisian of NW Scotland, and found only west of the Moine Thrust. The succession, which represents an enormously thick cratonic cover on top of the Lewisian basement, is divided into three groups, all Proterozoic (late Precambrian, or Neoproterozoic, 1000–750 Ma) in age. The youngest of these is the Torridon Group, which forms the characteristic red mountains in Torridon and Applecross (Figure 6).

Figure 6. Liathach, mountain in Torridonian Sandstone.

'Torridonian Sandstone' is the informal name for the entire sequence. It was previously considered that the Torridonian was laid down at the same time as the Moine sediments, but it is now thought that the two sequences had different source regions and that the Moine rocks were metamorphosed at 1050 Ma, before the Torridonian was deposited. The two have been juxtaposed along the Moine Thrust.

Figure 7. Boulders of Lewisian Gneiss in basal Torridonian conglomerate; Gairloch.

Torridon Group – 6 km of red arkosic sandstone, unconformable on the Lewisian

Sleat Group – 800 Ma; 3.5 km of coarse grey fluviatile sand stones and shales

Stoer Group – 1000 Ma; breccias, up to 2 km thick, filling in hollows in Lewisian

Torridonian clastic material was derived from the Lewisian (Figure 7) and from similar outcrops to the west, i.e. Greenland, and transported by rivers before being deposited as alluvial fan and braided river material at the margins of fault-bounded subsiding basins (rift valleys) – hence the great total thickness. Sleat and Torridon Groups are conformable and found in Skye, whereas the Torridon Group is unconformable on the Stoer Group on the mainland, and oversteps onto the Lewisian, onto an old land surface (Figure 8) which has now been exhumed, i.e. a buried landscape that formed after the Lewisian had been exposed, and has been brought to the surface again due to erosion. In other words, the topography at the time the Torridonian was being deposited was similar to that which we see today.

Figure 8. Slioch and Loch Maree, Wester Ross. Torridonian covering hillocks and valleys in Lewisian Gneiss basement; exhumed topography.

Cambrian and Ordovician

Finally on the foreland, above the Torridonian is a thin sequence of quartzites (including the Pipe Rock with its fossil worm tubes, Figure 9) and limestones (the Durness Limestone, Figure 10), lying above an unconformity. The Cambrian–Lower Ordovician sediments are tilted but must have been laid down horizontally at the edge of a shallow shelf sea, hence the Torridonian was tilted in the interval 700-570 Ma approximately, then restored to the

Figure 9. Cambrian Pipe Rock – worm tubes in quartzite; Loch Assynt.

Figure 10. Durness Limestone; Smoo Cave, Durness, North Sutherland.

Figure 11. Quinag, Assynt. Double unconformity – Lewisian in foreground covered by Torridonian on right, in turn overstepped by Cambrian quartzite on left.

horizontal. Sometimes these rocks overstep the Torridonian and rest directly on the Lewisian – forming the so-called 'double unconformity' (Figure 11). Fossils in these rocks, particularly trilobites, show similarities with species found in Canada, and not with those in Wales – an indication that there was an ocean barrier between Laurentia–Baltica and Gondwana at the time.

Moine Thrust Zone

Moine schists are in contact with rocks of the foreland along the Moine Thrust Zone, which marks the western edge of the Caledonian mountain chain (Figure 12). The thrust is located

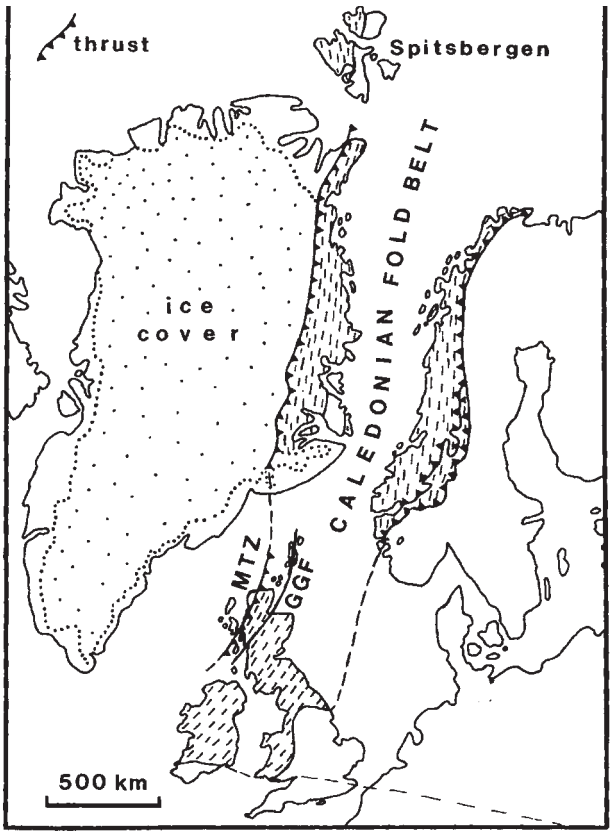

Figure 12. Reconstruction showing extent of Caledonian fold belt. GGF = Great Glen Fault, MTZ = Moine Thrust Zone.

Figure 13. Moine Thrust plane at Knockan, Elphin, Assynt. Moine schist on top of Durness Limestone.

along the bedding planes of the Durness Limestone (Figure 13), which acted as a lubricating plane at 400 Ma ago. Westward thrusting was the last great event in the orogeny. In the Assynt area there is a bulge in the thrust zone, related to the intrusion of a number of alkaline igneous bodies which effectively forced the thrust surface to become warped up. Altogether there are four major thrusts, from base to top (and oldest to youngest) the Sole Thrust, Ben More Thrust, Loch Glencoul Thrust (Figure 14) and Moine Thrust. Between each is a fold nappe with numerous minor folds and thrusts which repeat the beds, the whole making a major duplex structure. Each thrust may have had 10–20 km westward movement on it, and a total displacement of around 80km may not be an unreasonable estimate.

Figure 14. Loch Glencoul Thrust, Assynt. Lewisian above thrust, Cambro-Ordovician unconformable on Lewisian below.

Moine Schists

Metamorphosed Moine rocks cover most of northern Scotland east of the Moine Thrust Zone and north of the Great Glen Fault. They occur as three groups or divisions – Morar, Glenfinnan and Loch Eil – in a series of Caledonian thrust sheets. Most of the rocks belonging to the Moine Supergroup are thick units of grey and white striped psammite (quartzites – originally sandstones) and pelite (schists – originally muds), representing shallow marine sediments. Sedimentary structures such as cross-bedding are frequently preserved. They are completely unfossiliferous, and the banding is often folded (Figure 15). In places the rocks can be seen in contact with deformed Lewisian inliers, which would have formed the basement. Amphibolite sheets were intruded into the sediments as basic sills. Lack of index minerals means that it is difficult to assign a metamorphic grade to the Moine rocks, but they are likely to have been at greenschist–amphibolite facies. Metamorphic ages of 1050 Ma have been obtained, and it is possible that the Moine rocks were laid down some 1200–1300 Ma ago.

Figure 15. Folds in Moine schist; Monar dam, Central Highlands.

Dalradian Schists

In contrast to the Moine rocks, the Dalradian represents a highly varied sequence of metamorphosed late Precambrian rocks, totalling 25 km thick. Rock types in the four groups – Grampian, Appin, Argyll and Southern Highland – include quartzite, schist, limestone and marble (Figure 16), slate, phyllite, grit, volcanic

Figure 16. Folds in impure Dalradian marble; Cullen, Moray Firth coast.

rocks, including pillow lavas, and glacial tillite (boulder beds). Together they form a Supergroup that extends from Shetland in the north-east through the Grampian Highlands to Argyllshire in the south-west, then on to Ireland (Figure 12), occupying a total area of some 48,000 km^2. Dalradian rocks crop out between the Great Glen Fault and the Highland Boundary Fault, and are nowhere in contact with the Moine schists. They range in age from around 750 Ma to 600 Ma, with the Tayvallich Volcanics (596 Ma) at the top of the Southern Highland Group possibly representing the first rifting and opening of Iapetus – which therefore occurred just before the start of the Cambrian.

Highland Border Complex

Sporadically along the Highland Boundary Fault are narrow fault-bounded lenticular outcrops of weakly metamorphosed Lower Palaeozoic (early Cambrian to late Ordovician) sediments – limestone, black shale, sandstone, conglomerate and chert or jasper, with serpentinite, tuff and pillow lavas in places, such as at Stonehaven in the Highland Boundary Fault zone (Figure 17).

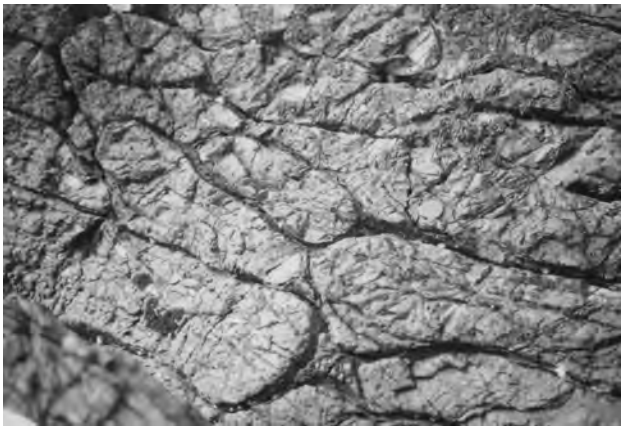

Figure 17. Pillow lavas in Highland Border Complex at Stonehaven in Highland Boundary Fault zone.

This tectonically disrupted rock sequence is unique and is difficult to correlate with other units in the Caledonian belt. The lower part of the Highland Border Complex may represent a fragment of an ophiolite which was obducted NW onto Dalradian rocks possibly during the Cambrian. Later the entire complex was slid along the Highland Boundary Fault by transcurrent faults.

Caledonian Orogeny

Northern Scotland can be viewed as a jigsaw puzzle, with the var-

Figure 18. Cairngorm granite plateau from summit of Cairngorm.

Figure 19. Folded Lower Palaeozoic greywackes; near St Abbs Head.

ious pieces locked together around 400 Ma ago, in the final stages of the Caledonian orogeny. Briefly, the events that took place were the intrusion of granite plutons at 405 Ma ago, including the Cairngorm massif (Figure 18), into the folded metamorphic rocks of the Highlands. Separate crustal fragments containing Moine, Dalradian and Highland Border Complex rocks were then slid into place along the Great Glen and Highland Boundary Faults, and the entire mass was transported north-westwards over the Moine Thrust onto the Lewisian and Torridonian basement or foreland. South of the Southern Uplands Fault and closer to the Iapetus suture, the rocks of the Southern Uplands – the folded Ordovician–Silurian deep oceanic turbiditic slates and greywackes of the non-metamorphic Caledonides (Figure 19) – became attached (as an accretionary prism or stack of thrusts advancing towards a subduction zone) by oblique collision between Laurentia and Avalonia as the Iapetus Ocean finally closed around 478 Ma ago.

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Book reviews

Molecular Evolution and Adaptive Radiation by T J Givnish & K J Sytsma (eds), 1997, Cambridge University Press, 621pp, £65.00 (hardback) ISBN0521573297.

This is certainly the epitome of an academic book, written for a few. In this case, probably fewer then five hundred and mainly those attending a symposium at McGill University in 1995, the proceedings of which this book is all about. As can be expected, the reader is thrown straight into the deep end, with no explanations of scientific terms. Although over 600 pages in length, many pages are taken up with references of papers and what appear to be cladograms on nearly every other page!

Each chapter contains a paper that was presented at the symposium. The first chapter is a history and introduction of adaptive radiation. This was the only paper I managed to read with ease and with full understanding. Much of this chapter contained details of Darwin and the Galapagos finches. It is the only place in the book where I found a definition of adaptive radiation, i.e. the evolution of a diversity of ecological roles and attendant adaptions in different species within a lineage.

The book tries to address the fundamental problem that, up to now in almost every case, the very characters whose radiation was under study (e.g. beak size and shape) were also used to help classify the organisms in question (e.g. Darwin's finches). This exercise can easily become circular, with traits being traced down evolutionary pathways determined, at least in part, by the traits themselves. Subsequent chapters include papers presented on such riveting subjects as evolution in the water hyacinths, adaptive radiation in Brocchinia and many papers on evolutionary convergence.

Certainly I found this book heavy going, despite having some knowledge of genetics and evolution; it is probably as exciting to read as a telephone directory! Unless you are very interested in adaptive radiation, I would give this esoteric book a miss.

Pauline Peirce BSc Hons (Open)

Satellite Mini Atlas of the World by S Butler, P Sackett, R Stacey, E Miller & E Stacey (consultants), 1998, AND Cartographic Publishers Ltd., Finchampstead, 159pp, £6.50 (hardback) ISBN 0953324605.

This mini atlas of the World measures 5.5” x 4” and is the tiniest atlas I have encountered. Data transmitted by orbiting satellites (e.g. NOAA) have been used to produce the images, colouring, shading and annotation provided the details for the lay reader. Based on a full-sized version (and excellent volume) this is designed as a “freebie” to which is added individual covers, in this case GEOU and, as such, is great fun. However, it is useless for serious cartographic applications. The only practical use I can think of is as an astronauts pocket guide to Earth landmasses and locations of major cities, lakes and mountain ranges etc.

There are a few pages of facts and figures: area of land and sea surfaces, lengths of rivers, populations etc. covering the top 10 in each category.

The final section consists of NOAA images of isolated features: lakes, rivers, islands, deserts, volcanoes and fracturing of the antarctic ice-shelf. Again false coloured images but, nevertheless, very realistic. This tiny book gets a tiny review, but it’s tiny enough to go into a stocking as a filler.

Jane Clarke, BA Hons (Open) MPhil (Open)

New finds in the Hopeman Sandstone

Carol Hopkins, Open University Earth Sciences Undergraduate

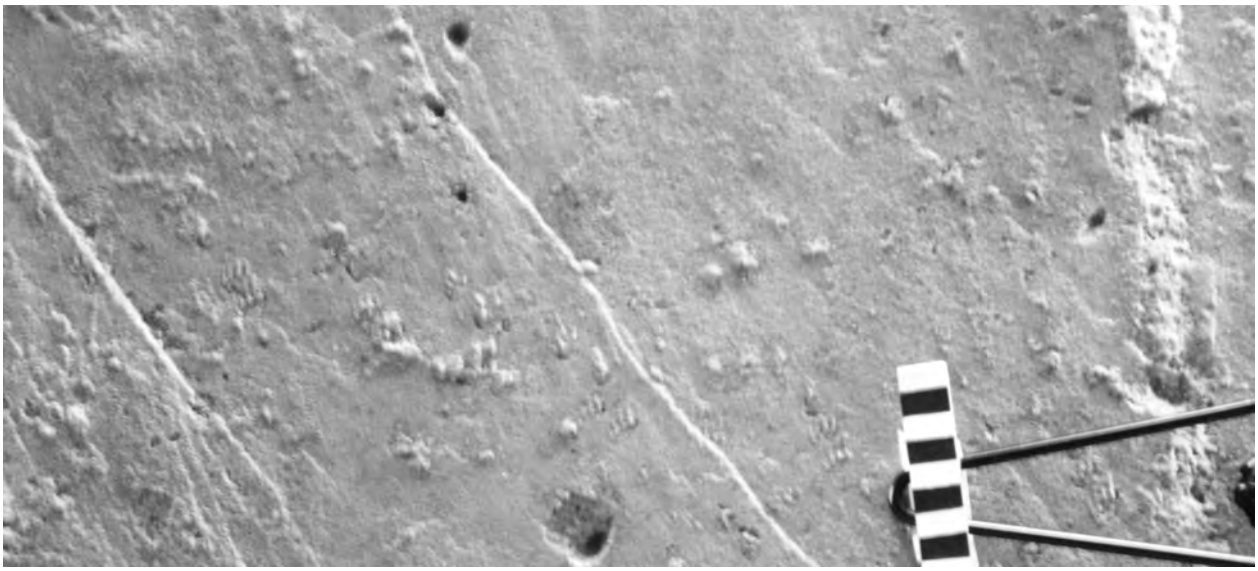

Figure 1. *In situ* natural cast of a trackway in the roof of the quarried undercut. Scale bar in cm.

Geological setting

The Permo-Triassic Hopeman Sandstone is around 60m thick, and outcrops north of Elgin for 10km along the southern shore of the Moray Firth, which was then a depositional basin. It is mostly exposed as sea cliffs between 10 and 30m high, and in small disused quarries. It comprises large scale aeolian dune deposits with corridors containing fields of smaller dunes or interdune flats (Clemmensen 1987). In some areas there are thin beds of pebbly water-laid sediments.

Footprint theft

At one locality small current ripples indicate the presence of an ephemeral stream or river. This rippled surface bore a tetrapod trackway that was known about for some time, but not recorded. I first saw the footprints in early November 1996 and found that one had been outlined with a rock-saw ready for removal and a carefully placed slab concealed the removal of what was presumably another footprint. Rock dust was still present and, as the area is below the mean spring high water mark, the removal must have occurred since the last such tide. I notified Scottish Natural Heritage (SNH) who in turn informed the National Museum of Scotland in Edinburgh (NMS). This evidence of surface water with trackways in an otherwise desert environment was considered important by NMS staff. They were concerned that the other footprints and consequently the rippled surface were still at risk.

Finally after consultations with SNH, the staff from the NMS removed the surface complete with the remaining footprints in February 1997. Part of the surface is now on display at the National Museum, and a small area of ripples remains *in situ*.

History of research and finds

Many tetrapod trackways and footprints were found in the latter part of the 19th century, when there were numerous quarries operating. Many eminent workers at the time visited or published on the Hopeman Sandstone including Thomas Huxley (1877) and Murchison (1859).

The identity of the trackmakers is not known as no body fossils have been found, apart from a tiny unidentifiable fragment of bone found at Greenbrae Quarry during the revision survey (Peacock *et al.* 1968). The Upper Permian Cutties Hillock Sandstone Formation of Elgin has yielded fossils of mammal-like reptiles, the dicynodonts *Gordonia* and *Geikia*, and the pareiasaur *Elginia*. It is thought that the Hopeman trackways were made by two or more mammal-like reptile genera, possibly dicynodonts (Haubold 1971). As the footprints were preserved usually with a mound of sand behind, the animals were interpreted as moving up dune foresets.

New finds

Footprints can still be found today in the spoil heaps from the old quarries, and there are 13 tetrapod trackways and an invertebrate trackway *in situ* in the roof of an undercut excavated at a disused quarry. The trackways are on 5 separate beds with dip angles between 19° and 21°, and are digitigrade or plantigrade with footprint widths of 1 to 11cm. A digitigrade stance had not yet evolved at the end of the Permian and the foreshortened prints may be a result of the animal digging its toes in as it moved up the dune slope. If the trackway is subsequently preserved, or exposed as an undertrack, only the deeper toe impressions may be evident.

A single bed within the overhang has 8 trackways, including a single trackway 3m long with over 200 digitigrade prints of 4 and 5 toes (Figure 1). The toe direction is at odds with the general direction of the trackway where the animal was evidently walking sideways. This has been observed before on loose slabs in museums and has been attributed to an animal too small to ascend a slope directly, following an easier sideways path (McKeever & Haubold 1996). However, this has not been observed *in situ* until now and this trackway certainly supports that hypothesis. The general dip of the formation varies between a few degrees and 8° (Clemmensen 1987) and this bed has a dip of 21° with the toes heading upslope.

Figure 2. Pentadactyl footprint from Clashach Quarry. Coin - 25mm.

In 1996 there was an increase in operations at Clashach Quarry to provide facing stone for the extension to the National Museum in Edinburgh. Excavations have resulted in the discovery of over 250 new tracks or trackways and the range of form and size of the tracks is significant.

The first finds were from a spoil heap from a fault zone in the centre of the quarry face. The footprints ranged in size from 2cms to 18cms, mostly preserved as digitigrade prints of 5 toes or claws (Figure 2). Many display pairing of the front and back feet, where the back foot falls close to, or even oversteps, the impression left by the front foot.

Trackways then started turning up in all parts of the quarry during excavations. Most of the trackways are between 1 and 4m in length, this is attributable to the blasting technique which preserves massive blocks. A large block with the natural mould and corresponding cast of 6 trackways was found in the eastern part of the quarry. The trackway prints were generally of similar size, which might have implied herding behaviour. However, closer inspection revealed varying depths and clarity of preservation of the track indicating that they were made on different layers of substrate with time intervals between trackmaking events. Tail drags were then found in the western part of the quarry face, notably a 3m long sinuous tail drag with a pigeon-toed gait, similar to some modern reptiles. In most cases the tracks appear to be heading upslope as there is usually a mound of displaced sediment behind the footprints. On a slab with over 200 footprints and 21 tail drags there is one particular trackway and tail drag with unusual features (Figure 3). The footprints are all pointing to the right of the midline of the trackway with pronounced lateral rota-

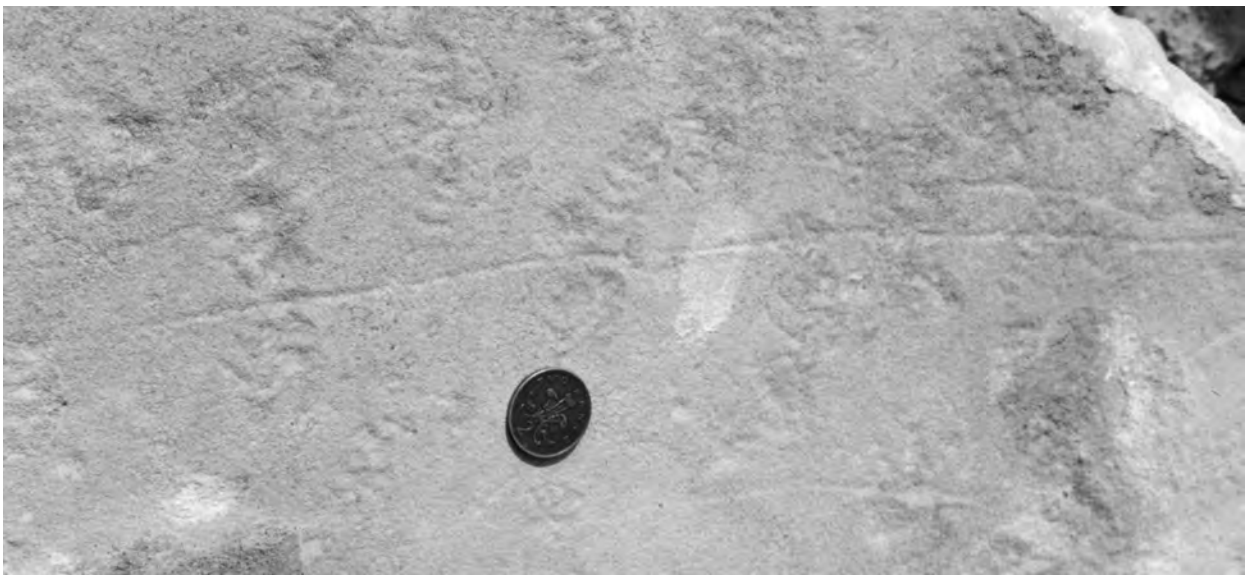

Figure 3. Trackway with associated tail drag, displaying features consistent with the trackmaker moving across a dune slope. Scale Coin - 25mm.

Figure 4. Trackway with associated tail drag, displaying features consistent with the trackmaker moving across a dune slope. Coin - 25mm.

tion of the left feet and a mound of sand to the left of each footprint. This is all consistent with the trackmaker moving across a dune slope slipping downslope slightly, using a more propulsive kick-off stroke on the downslope side (the left) to maintain its purchase and direction across the slope. Another slab has a trackway with a tail drag lying to one side of the midline of the trackway, again indicating that the animal was moving across a dune slope with the tail trailing on the downslope side (Figure 4).

A trackway with long claw scrapes 13cm wide also suggests an animal slid downslope or trailed its claws as it walked down a dune. On the same slab is a 1.5cm wide furrow with footprints either side. This would suggest a tail drag, but it was wider and straighter than observed previously. The probability of excavator damage was dismissed as there was a ridge along the edge of the furrow which could only have formed in unconsolidated sediment (Figure 5). This was subsequently confirmed by the discovery of the counterpart cast of the trackway complete with tail drag. Then more of this type of tail drags were excavated; they were up to 2cm wide with clearly associated footprints or claw marks. The discovery of all these tail drags was significant as only 4% of all Scottish Permian trackways were previously associated with tail drags (McKeever 1994). There are now 105 tail drags from Clashach, some 42% of current trackway finds at this locality.

Figure 5. Claw scrapes and trackway with associated tail drag. Coin - 25mm.

Many of the trackways have surprisingly short stride lengths, given the width of the footprints. Stride length is related to leg length and speed, but an animal also takes shorter steps when moving uphill. The trackways with short stride lengths are usually associated with displacement of the sediment behind each footprint, which is consistent with the animal walking up a dune slope (Figure 7). The notable feature of these trackways is the narrow trackway width. Interpretations of Permian tetrapods exhibit a very sprawling gait similar to modern reptiles; yet, in many trackways, the distance between left and right feet barely exceeds the width of the footprint. If the trackmakers had a sprawling stance, the feet would have been placed close to the midline of the body during locomotion to achieve such a narrow trackway width.

Many of the footprints do not reflect the size of the foot; slippage of the foot during walking can distort the print, and overstepping of front and back foot can create the impression of a single larger print. Undertrack footprints may appear larger as the print can be exaggerated through several layers of sediment.

In September 1997 Professor Hartmut Haubold of the Martin-Luther University in Halle, Germany visited the quarry. He considered two trackways on one slab to be particularly interesting. The trackways demonstrate that a smaller animal (footprint width 3cm) must reduce the angle of ascent of a slope by traversing the dune laterally, whereas a slightly larger trackmaker (footprint width 4cm) was able to move directly up the slope.

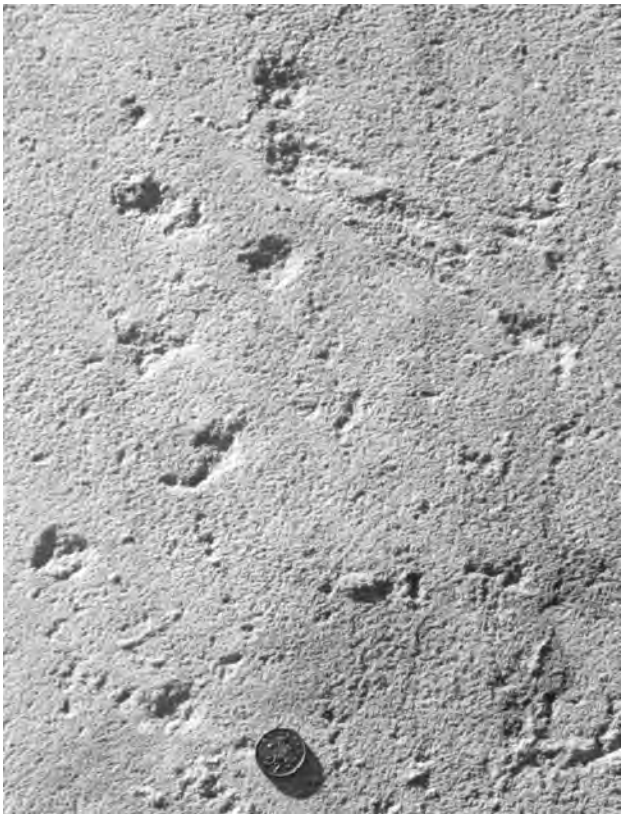

Figure 6. A trackway of 2cm wide circular impressions with a very regular trackway pattern terminates with 2 closely spaced footprints on one side of the trackway, indicating that the animal changed direction abruptly. Long parallel furrows grouped into four suggest that the animal started to slide downhill, digging its toes in to slow its descent. The pattern of grooves suggests that the toes splayed out and dug deeper until the animal finally came to halt. Coin - 25mm.

Figure 7. Natural cast of a trackway with relatively short stride length and narrow trackway width, displaying clear pairing of the front and back feet. Coin - 25mm.

Professor Haubold is an authority on trackways and considered the quarry to be an important locality for several reasons: the range of footprint types, the number of trackways on different horizons, and the length of the trackways with differing quality of preservation within a single trackway. The latter is particularly useful when classifying footprints, as some footprints with apparent morphological differences have been assigned various ichnospecific names in the past when all that differed was the type or quality of preservation (McKeever & Haubold 1996). Within longer trackways there may be a variation in locomotion, gait or substrate properties, resulting in heterogeneous preservation.

In situ tracks

Constant monitoring of the quarry and the enthusiastic cooperation of the quarry operators has provided a rare opportunity to record many *in situ* trackways prior to excavation. The *in situ* trackways are on beds with dip angles between 18° and 21°, with the tracks all trending perpendicular to the strike of the beds. Anecdotal evidence from the last century gives the tracks all heading north towards the Moray Basin. There are 21 *in situ*

Figure 8. The western part of Clashach Quarry; the cleared beds bear *in situ* trackways. Bill George, the quarry manager, for scale (in foreground).

trackways with discernible headings both here and at other localities throughout the Hopeman Sandstone. Typically the headings are between 305° and 65°, with 3 on a single bed in a disused quarry heading between 75° and 90°. Evidently the topography of the dunes would have dictated the trackmaker's path, but why are no footprints observed heading south? Permian trackways in Dumfries and Galloway are reported to be heading south towards the Solway basin. It has been suggested that this was part of a migratory route to seasonal water and the dune environment was not the normal habitat of the trackmakers (McKeever 1994) and this might be the case at Hopeman. However, it may simply be due to preferential preservation. A daily or seasonal movement to water or vegetation in the Moray Basin when the sand was dampened by rain or dew and slightly consolidated, ideal for trackway preservation with the animals returning when the sand was dry and their tracks were easily reworked. Evidently the trackways can provide environmental and behavioural indicators, and the data collection gives a general impression of the range of size, form and gait of the fauna.

A newly exposed area of the wave cut platform at Hopeman foreshore revealed superbly preserved pentadactyl 1cm wide footprints and tail drags. Many of the tail drags are intermittent, consistent with the tail bouncing during locomotion. The rest of the bed had been exposed for some time, but the badly weathered tail drags were unidentified and caused considerable puzzlement on many field trips.

Display area

As mentioned earlier, the cooperation of Moray Stone Cutters, the quarry operators, has contributed greatly to this study. They assured me that they have quarried many slabs in the past that evidently bore footprints, but at the time they were unaware that they were trackways. Not only have they preserved trackways until they were recorded, they are also responsible for many of the finds and have constructed a display area adjacent to the quarry to house trackways not destined for museums. An interpretation panel is now installed at the display area, a joint project between Moray Stone Cutters, myself, NMS and SNH. The project is the recipient of the 1999 Lasmo Geological Challenge Award.

Body fossil

In August 1997 a block of sandstone some 3m long was excavated from the top of the quarry face. The block was considered too large for transportation, so the stone was split and revealed an anomalous cavity inside. We were actively looking for fossil remains and the quarrymen always set aside anything unusual to be examined and joked that they had found me a fossil on my next visit. Unable to believe that after 150 years of recorded geological interest in the Hopeman Sandstone we had actually found fossilized remains, but aware that the Elgin reptiles were preserved as moulds, I contacted Neil Clark at the Hunterian Museum in Glasgow. He agreed to investigate the fossil before returning it to Elgin Museum.

Acknowledgement

My research continues with the support of the National Museum of Scotland and Moray Stone Cutters, and I'm currently working on the formal descriptions and classifications of the tracks. The work presented here will form part of a PhD research project.

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Book reviews

Geology of the country around Inverurie and Alford by D Gould, 1997, BGS, 116pp, £45.00 (paperback) ISBN 011884525X.

This memoir for the 1:50000 GS Sheets 76E and 76W describes an area west of Aberdeen which lies within the Caledonian orogenic belt. The geology is metamorphic and igneous with a small amount of sedimentary rock. The volume has 12 chapters of which nine deal with the metamorphic and igneous rocks

As well as a colour photograph of Bennachie (granite) which begins the volume, there is some colour in the various diagrams and figures throughout the volume. A geologist or even a budding student would find the book useful and it is certainly one I would like on my shelves. There is much detailed information within its pages. I rather like Figure 6 which is a "blown apart" block diagram of the Dalradian rocks of the north east Grampian Highlands, which very neatly laid out the structure. Top prize, however, goes to Figure 26, stratigraphic sections at Quarry Hill, which I would be happy to frame and hang on the wall. There is a section on the Rhynie Cherts which I was particularly interested to read and many more descriptions of the geology of the area.

The print is clear and there is a good reference section as well as an index. Appendices are on boreholes, GS photographs, fossils from the Devonian and various BGS reports. If I have any complaint it is that the thin section photographs could have been larger, but no doubt those with younger eyes than myself would think I was nitpicking here.

Doreen Smith BSc and continuing Earth Science student

Fluid Flow and Transport in Rocks: mechanisms and effects by B Jamtveit & B Yardley, 1997, Chapman & Hall, 319pp, £75.00 (hardback) ISBN041273405.

The flow of fluids, whether gas, liquid or supercritical, occurs in a wide variety of geological environments. For example: fluid flow is initiated in sedimentary basins during compaction and diagenesis, igneous intrusions can induce circulation of groundwater and fluids are produced during prograde regional metamorphism. Interaction between fluid and rock occurs during flow; for example, permeability may increase due to solution or hydrofracturing or may decrease as minerals are precipitated This book records the proceedings of a seminar held in Norway in 1995 which brought together process-orientated researchers studying both the physics and chemistry of fluid flow and transport in rocks. It provides a state of the art review of the area and gives a good insight into the complexity of the problem together with our ability to understand and model this complexity.

The content of the book is organised into three main parts. The first seven chapters concentrate on the role of fluids in specific geological environments, ranging from sedimentary basins to regional metamorphism. The next four chapters focus on those properties of the fluid-rock system that are critical in controlling flow and transport. The final five chapters are concerned with modelling and simulation of flow and transport. As a chemical engineer I found this part of the book particularly interesting. Although this book contains some fascinating insights, it is not an easy book to tackle; even the introductory chapter is heavy going, with partial differential equations making a debut on page 6! The book will be of interest to people who are well on in their OU earth science studies, especially if they have a strong background in maths and physics. The book is well produced in clear text and with good diagrams and photographs; so it should be at the price!

Duncan Woodcock BSc Hons, continuing Earth Science student

Carl Sagan's Universe by Yervant Terzian & Elizabeth Bilson (eds), 1997, Cambridge University Press, 282pp, £14.95 (paperback) ISBN05215763032.

Halfway through this book I thought how interesting it was. I had been given an up-to-date resumé of the present state of planetary exploration and a philosophical appraisal of man's place in the universe. This was accompanied by some excellent photographs both in black and white and in colour. The book is a record of papers given at a symposium to honour Carl Sagan's sixtieth birthday in 1994. It is to the editor's credit that they have published so quickly, particularly since Sagan died untimely in 1996. One can see from Sagan's address to the symposium just how outstanding was his ability to communicate scientific ideas to lay people, a gift which he had used so effectively in his television series Cosmos. So it should not be surprising to find the second half of the book concerned with science education and the relationship of science to politics and religion. After all, Sagan had been a great crusader on such issues as nuclear winter, global warming and the misuse of scientific knowledge. He had helped politicians to recognise the futility of the arms race in a world economy that was educationally and nutritionally unbalanced.

My slight misgiving is that the second half of the book is, despite Sagan's own Weltanschauung, a little too homely, even including a chummy symposium of the editors with the great man. Nevertheless, as I intimated at the beginning, there is much of interest in these pages and different people may derive from its various ideas encouragement in their chosen fields.

The ability to communicate science to people is a gift that has been sadly lacking in recent years when the political management of information on AIDS, salmonella, BSE, global warming, overpopulation, radon, atomic power, smoking and cancer has been so lamentably poor. Unless people are better able to understand these matters they will rush, like rats in a barrel, from apparent crisis to apparent crisis as a sensation-seeking press drives them. We have great need for more scientitis with Carl Sagan's gift of communication. This is a fitting tribute.

Tony Sheehan BSc Hons.

The Elgin Marvel

Neil D. L. Clark
Hunterian Museum, University of Glasgow, University Avenue, Glasgow G12 8QQ

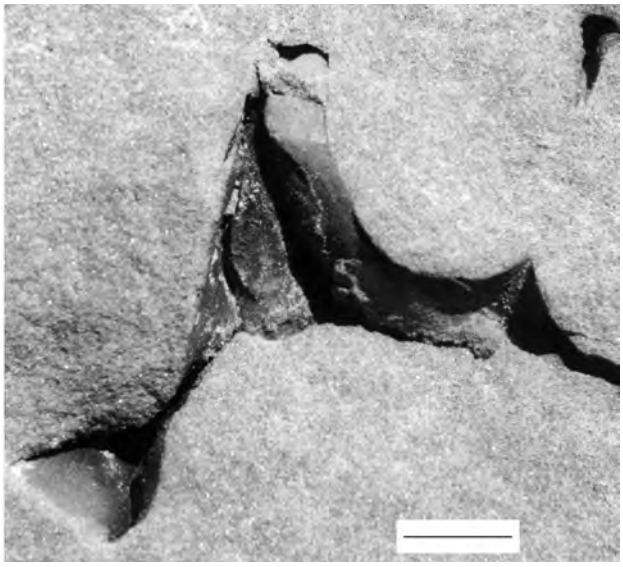

Figure 1. The fossil mould in Hopeman Sandstone. Photo: Carol Hopkins. Scale bar 20mm.

Introduction

In 1997, on splitting a large block of sandstone, the Moray Stone Cutters at Clashach Quarry observed a hole in the rock. Realising the potential importance of this discovery, the quarrymen set the rock to one side and contacted local expert, Carol Hopkins. After a preliminary examination of the hole in the sandstone by Carol, it was decided that the hole could represent the mould of fossil bone (Figure 1). In desert environments, bones tend to bleach white (oxidising of the organic content) leaving only the mineral content of the bones. In the case of the Clashach Quarry mould it appears that after the bones had oxidised in the Permian desert, acid waters flowing through the sandstone dissolved the rest of the bone to leave a void.

The importance of this fossil mould is that it is the first fossil from the Hopeman Sandstone Formation which has a potential for dating the rock formation more precisely than has been previously possible. The Hopeman Sandstone Formation has been variably placed in the Devonian Period, but many authors suggest either a Permian or Triassic age (Watson & Hickling 1914, Peacock *et al.* 1968, Walker 1973, Glennie & Buller 1983, Benton & Walker 1985, Glennie 1985, and Clemmensen 1987). The Hopeman Sandstone Formation has also been broadly correlated with the Cutties Hillock Sandstone Formation (Walker 1973, Benton & Walker 1985 & McKeever 1994).

Methods

Dicynodon (*Gordonia*) and *Elginia* are found at Cutties Hillock near Elgin, also preserved as moulds. Traditionally these moulds of fossil animals were cast in rubber by filling the holes and splitting the rock (Benton & Walker 1981). To avoid damage to the mould, non-invasive techniques were employed using modern medical scanners. From previous experience of non-invasive techniques used to examine dinosaur eggs, CT-scanning was performed in the first instance. From the first scan it was obvious that we were dealing with the entire skull of a mammal-like reptile (anomodont). Rendering the CT-scans produced a 3-D image of the skull which, if the bone was still there, would have been one of the most complete dicynodont skulls known. One of the advantages of this technique is that it is possible to selectively remove parts of the skull to allow examination without obstruction (eg. removing the lower jaw to reveal the palate (Figure 2c; Figure 4).

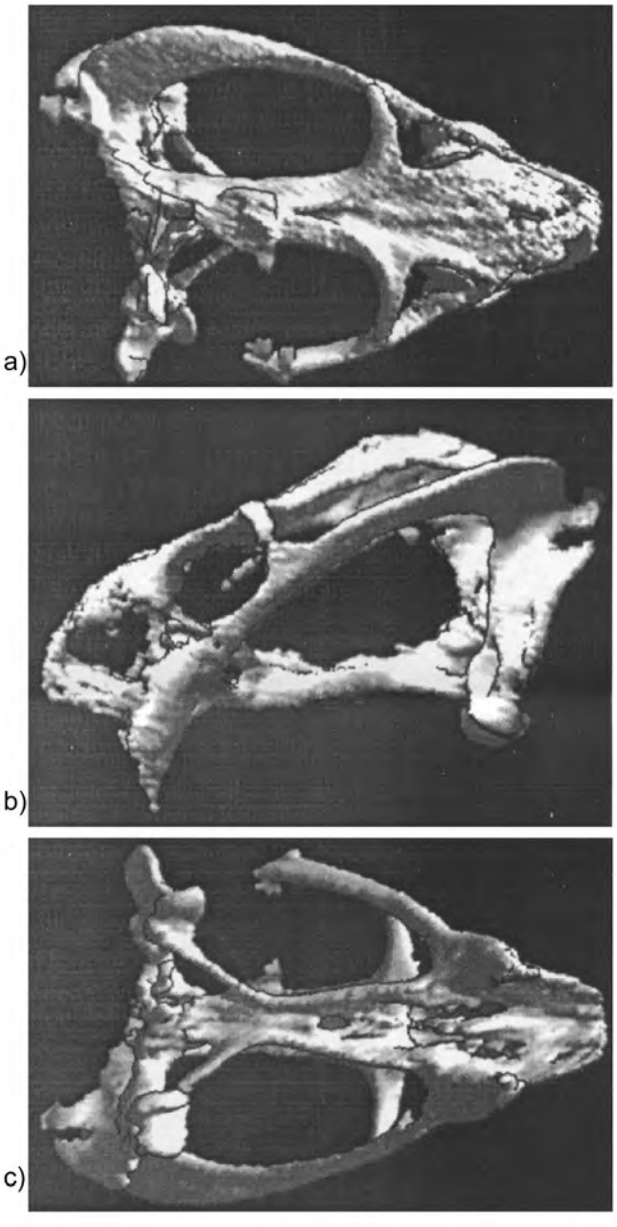

Figure 2. CT-scans of the skull in a) dorsal, b) left lateral and c) ventral view (skull approximately 26cm long).

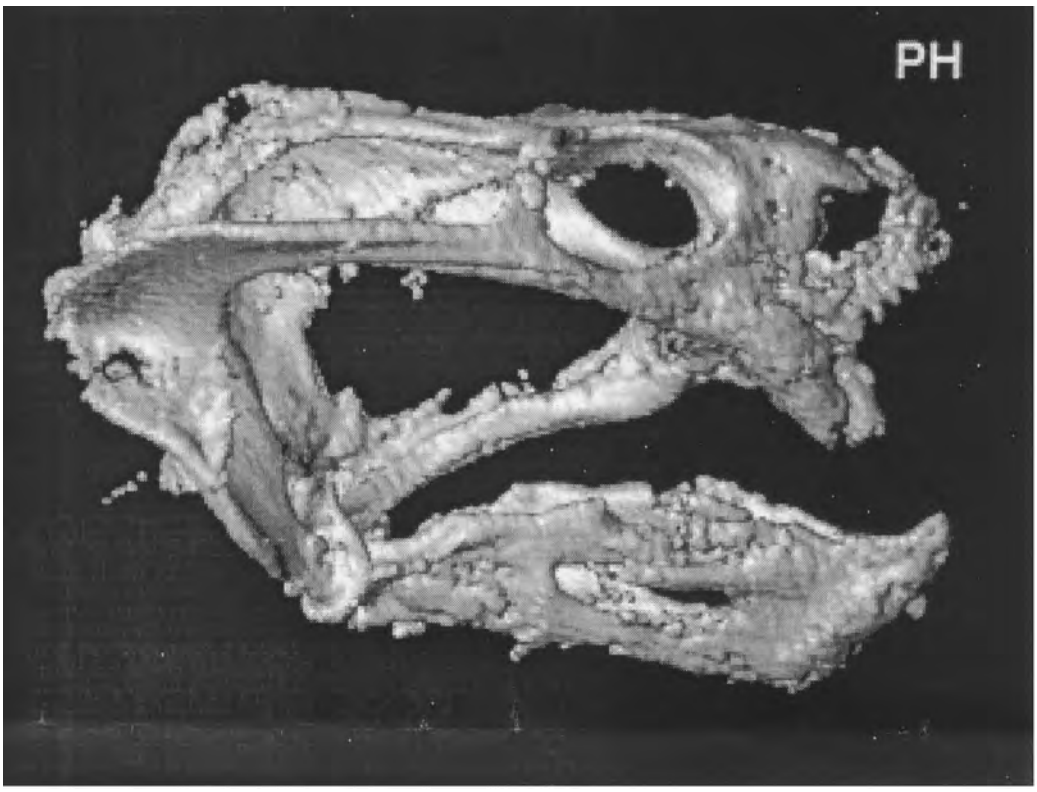

Figure 3. Right lateral view of skull with lower jaw using MRI.

MRI-scanning could provide a better resolution than CT-scanning because of the finer scan thickness. To be detected, the cavity had to be filled with water prior to scanning as MRI requires a fluid to react with the magnetic field. The results from a preliminary scan were encouraging; however, the lower jaw did not show on the scans as it was not connected to the rest of the skull and water did not penetrate to fill the void. CT-scanning was used to pinpoint the precise point of the sandstone block to drill a hole. The hole then allowed water penetration into the lower jaw. The entire skull was then successfully scanned using MRI (Figure 3). The rough edge on the MRI images is, in part, caused by minute bubbles trapped within narrow gaps and the interface between the void and the sand.

Results

From these images it has been possible to identify the fossil as a species of *Dicynodon. Dicynodon* is a mammal-like reptile that is found in Russia, Europe and southern Africa from the Upper Permian. As this is the first recognisable mouldic fossil bone from the Hopeman Sandstone Formation, it is also the first time that the age has been determined for that formation. Differences in the position of the eyes, the angles of the post-orbitals, suspensorium, 'canine', zygomatic arch and the shape of the nasals from *Dicynodon* (*Gordonia*) may have more to do with post-mortem compaction of the bones than any original variation. Further research may show this to be so.

The use of medical scanners has saved a very important fossil from being damaged by traditional methods of palaeontological investigations. The resolution obtained is enough to identify the species of dicynodont represented by the mouldic skull. In some parts of the skull, fine structures that would have been lost using rubber casting techniques were observed. The images were manipulated easily on computer to view the inside of the skull, to remove the lower jaw, and to look at parts of the skull in all orientations.

Acknowledgements

I would like to thank the Moray Stone Cutters, the two Bills, Gavin and Dave, who discovered the fossil, and Drew Bailey without whose permission to collect the fossil the age of the Hopeman Sandstone would still be a mystery. I would also like to acknowledge Carol Hopkins for bringing the fossil to my attention and for all the help she gave, Dr Sue Warbrick of the SNH, the Glasgow hospitals of the Western Infirmary, Gartnavel and Royal Infirmary who made their scanners available and Dr Calum Adams who made it all work, Dr Arthur Cruickshank for helping with the identification, and Stuart Fairley for organising the conference in Aberdeen.

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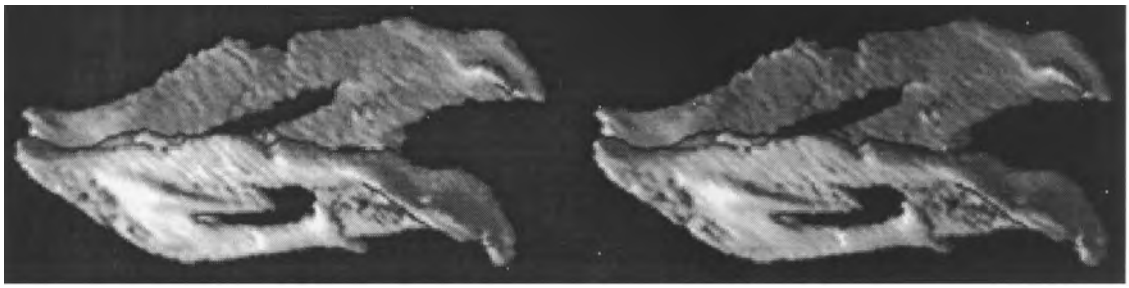

Figure 4. Stereoscopic pair of the lower jaw after the skull has been digitally removed.

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Book reviews

Sea-level changes: the last 2000 years by Pirazzoli P A, 1996, John Wiley & Sons, 211pp, £24.95 (hardback) ISBN 0471969133.

Sea-level and the land mass rise and fall relative to each other. They can go up or down together at the same or at differing rates. They can go in opposite directions at the same or different rates, in fact they can move in any combination you care to think of. This book looks at the ups and downs, the reasons for them and how to recognise the evidence for the movements.

Evidence for movement can be biological, erosional or depositional. The marine zones (littoral, midlittoral and sublittoral) are explained along with how to identify ancient zones. The formation of erosional indicators (notches, benches, tafoni, potholes and honeycombs to name a few) are explained along with photographs of most features mentioned. Depositional indicators (reefs and sedimentary shorelines) are given the same coverage but with several illustrations of how the shore lines built up. The section concludes with the use of archaeological and historical data as sea-level indicators.

Having looked at the evidence for sea-level changes Pirazzoli moves on to look at the causes, he begins with the ice age earth and the positions of sea-level during the last glaciation. The evidence for low-sea-level land bridges and landscapes are examined including mankind and mammalian migrations. Several diagrams are used to aid understanding of theories in this section; I was left wishing I could colour them in to aid clarity.

The two major steps in deglaciation and its effect on sea-level changes were next examined. The theories and the global isostatical models were discussed, along with regional case studies. Relative changes in Late Holocene and current sea-levels brought the material up to the present time. Diagrams, tables and photographs were included to back up the theories and aid understanding.

An interesting book that gave me a greater understanding of sea-levels and their relative movements. The photographs used illustrated clearly the features talked about in the text and I felt I would easily recognise them when confronted with them in the field.

Glynis Sanderson BSc Hons (Open), PG. Dip LIS

Physics and Chemistry of Earth Materials by Alexandra Navrotsky, 1994, Cambridge University Press, 417pp, £22.95 (paperback) ISBN 0521358949.

It was the illustrations in Chapter 2, Crystal Chemistry, which attracted me to this book; they reminded me in some ways of the drawings by M C Escher. This book is intended for final year undergraduate and first year graduate students. To get the most out of it you will need to have studied both chemistry and physics in second year (and done well at them!) and should be at least acquainted with the principles of calculus. Having said that, the book is remarkably easy to read and carries you along rather like a novel in places. Diagrams are used freely to illustrate the text and tables provide much useful data.

Chapter 3, Experimental methods for studying structure, and Chapter 4, Methods for studying thermodynamic properties, give very good accounts of the techniques and apparatus used to measure the properties of earth materials without descending into tedious detail.

Chapter 5, Chemical Bonding, deals with three major approaches to the subject - the physics approach, the chemistry or molecular approach and the mineralogy or ionic approach. It is here that your knowledge of quantum physics and mathematics will really be required! Talking of quantum physics, the author feels that quantum mechanics abounds with uncertainty principles and describes three. The last of these may seem funny .... but not if you've been there! "as soon as a user has mastered a computational method, bigger, faster and cheaper computers and more clever and economical ways of doing the calculations become available."

Chapter 6, Mineral thermodynamics, is where some familiar earth science appears in the form of high pressure phase transitions and the earth's interior. Chapter 7, Solid solutions and order-disorder, puts the theory around another familiar concept and Chapter 8, Melts, glasses, and amorphous materials deals with some of the properties and behaviour of non-crystalline solids.

Structural distortions, defect chemistry and impurities affect elastic constants, thermal and electrical conductivity, rheology, diffusion rates and other physical properties. Such properties determine the manner in which the planet evolves. Anyone wanting to understand that evolution will find that this book forms a very good bridge between their undergraduate and postgraduate studies. At £22.95 it has to be a Good Buy!

Martin Elsworth

The Aftermath of the Groningen Gas Discovery: History of North Sea Exploration 1964 - 1999 in 30 minutes

Dr K W Glennie, University of Aberdeen

I am going to talk about the history of North Sea exploration since the discovery of the Groningen gas field forty years and one month ago - the last day of May 1959. It was discovered by the Slochteren Number 1 Oil Well in the Netherlands which had the Zechstein as its target horizon. The drill only just managed to hit the field; if the bore had been a little more to the left in Figure 1 (south), it would have missed it. At the time only the top of the salt was seismically visible so it was lucky to have drilled on the culmination of the salt.

Before any exploration could start the North Sea had to be divided up into national areas with 'median lines' between them. Britain controlled virtually half the North Sea whilst Norway, Denmark, Germany and the Netherlands had their own sectors in the eastern North Sea (see Figures 2 & 6).

When exploration started at the end of 1964 a lot was known about the geology of the land areas of North-west Europe but the North Sea was just a white, blank area on the map. The Russians published a map in 1976 showing some of the Zechstein diapiric structures; a little was known about them in the southern North Sea but nothing further north. Since 1959 a lot of the blank area has been filled in.

Consider the core sections from near the base of the Rotliegend System (fig. 5.11 & 5.12 in Glennie 1998) showing conglomerates covered with some foresetted dune sands dipping to the west: the other sediments are probably fluvial and there are a lot of almost homogeneous sands, the origins of which are more difficult to interpret. The dune sands are generally sub-horizontal at the base then the angle of inclination steepens upwards until it is truncated by another sub-horizontal sand sequence, and so on.

The calculations made immediately after the discovery of the Slochteren Well suggested it was in a field similar in size to BP's West Sole field found later in 1965 - containing 2 trillion cubic feet of gas. It is now known that the Groningen gas field holds just over 100 trillion cubic feet of gas, fifty times bigger than West Sole.

So where did we drill? The first well drilled on the Mid North Sea High was dry and abandoned, as were the second and third wells. Wells had to be drilled in the Mid North Sea palaeo high as it was the biggest structure seismically visible in the North Sea and might have contained oil or the target of gas, and the age of the rocks had to be determined. The fourth well, drilled by BP, found the West Sole field, then Shell found the Leman Bank field and in a very short time there were quite a number of oil and gas fields in the southern North Sea (Figure 2 and Table 1).

No drilling could take place in the North Sea until each bordering country had signed the International Continental Shelf Convention of 1958. Britain signed in 1964 and could then start drilling.

There was so much gas in the Groningen gas field that there was no hurry for the Dutch to get gas from off-shore, so it was not until 1968 that they signed the International Convention on median lines and could begin offshore drilling. But the Dutch had already learnt a lot about what the British were doing and located a gas field with their first offshore well in 1968, followed by other gas fields in 1969, 1970, 1971, 1972. In 1970 and again in 1971, they also found oil, which does not occur in the UK sector; oil is derived from a Jurassic source rock that is not mature in UK waters but is mature in Dutch waters. So the Dutch got off to a very good start (Figure 2).

The UK fields developed were: West Sole with gas reserves of 57 billions of cubic metres; Leman Bank, about 11 trillion (10^{12}) cubic feet ($316 \times 10^9 m^3$), over five times bigger; Hewett, half the size of Lemon Bank, and Indefatigable which was slightly bigger than Hewett (Table 1). In UK waters the gas had to be sold to a monopoly state market and by 1968 the market was virtually flooded, so no more exploration took place in that area. The seismic ships moved northwards and began exploring the northern North Sea.

Ekofisk, a chalk field, was the first important field in terms of volume, discovered by Phillips in the northern North Sea in Norwegian waters, and then BP discovered the Forties field, a

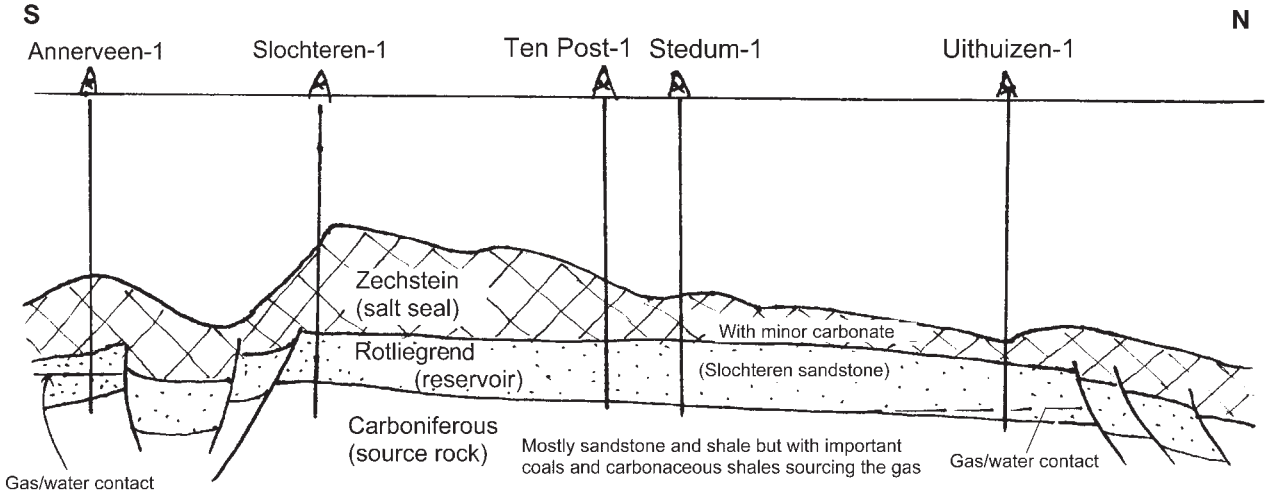

Figure 1. Groningen gas field: discovery well Slochteren-1; sketched from seismic data.

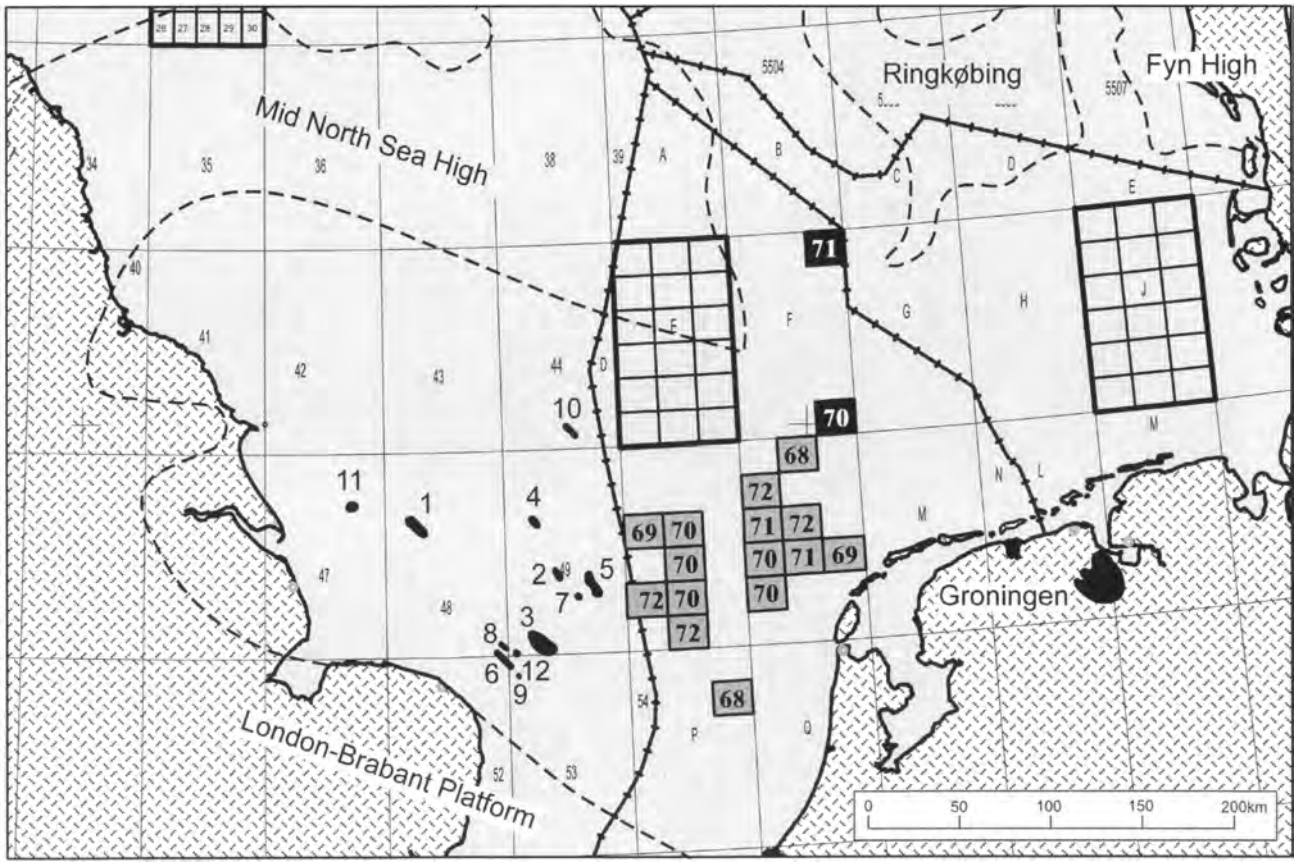

Figure 2. The order and distribution of gasfield discoveries in the UK southern North Sea, 1965-1968; the Netherlands offshore discoveries are given by year, 1968-1972, as their exact order is not known.

ORDER OF DISCOVERY	FIELD NAME	DATE	OPERATOR	RESERVES 10^9 m^3
1	WEST SOLE	DEC 1965	BP	57
2	VIKING B	DEC 1965	CONOCO	79 (total Viking)
3	LEMAN	APR 1966	SHELL/ESSO	316
4	ANN	MAY 1966	PHILLIPS	?
5	INDEFATIGABLE	JUNE 1966	AMOCO	131
6	HEWETT	OCT 1966 NOV1966	ARCO MOBIL	115*
7	INDE SW	JUNE 1967	AMOCO	2
8	BIG DOTTY	SEP 1967	ARCO	See Hewett*
9	CAMELOT N	NOV 1967	MOBIL	6 (incl E & N)
10	CAISTER (BUNTER)	JAN 1968	TOTAL	11
11	ROUGH	MAY 1968	BRITISH GAS	11
12	DEBORAH	AUG 1968	PHILLIPS	See Hewett*
			TOTAL	**>649**

Table 1. Order of gasfield discoveries UK southern North Sea. Although the precise order of discoveries is not known, in the first three years of exploration in the Netherlands offshore ten fields were discovered, nine gas and one oil. Within another two years those totals had increased to sixteen and two respectively, the volume of recoverable gas amounting to about 170x10^9m^3 (Breunese & Rispens 1996)

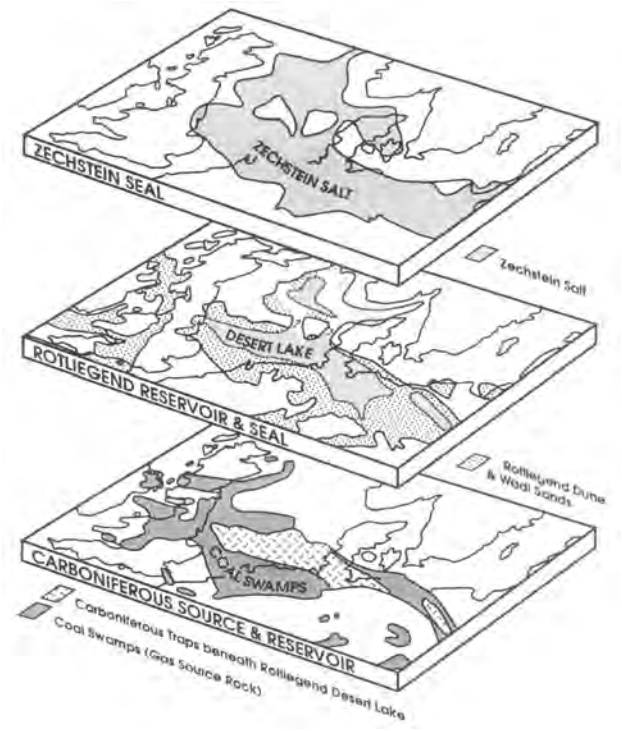

Figure 3. Stratigraphic levels showing the source rock, the reservoir rock and the top seal of the Rotliegend.

major field of 2 billion (10^9) barrel recoverable oil, which really started things moving.

I made a geological map in 1970 of the Rotliegendes facies distribution based partly on what had been published in Germany. It showed that we knew little north of the Mid North Sea High (Glennie 1972). By 1970 the Forties field had been discovered in the northern North Sea but, because of competitor advantage, the field's details were not published. To keep your knowledge to yourself was a distinct commercial advantage. I included palaeo-wind directions on the map, so there was a westward-pointing arrow at Groningen.

There was fairly rapid development in uncovering the Permian geology of the southern North Sea. There were dune sands down in the south with fluvial gravels cutting through them (especially in early Rotliegend time) overlain by dune sands. In the middle there is a desert lake with sediments up to 2,000m thick in Germany and so arid that it had its own halite horizons, each up to a hundred feet thick. The lake was about the size of the Caspian Sea in area, fed mostly from rivers, but the basin was subsiding so fast that the floor of the basin was below the regional water table and that provided a lot of the salt water necessary for evaporation in these arid conditions. The Central, Horn and Viking Grabens were already beginning to form in the Late Permian, and there were dune sands in the Moray Firth area and some in the southern Viking Graben.

A map from the 1998 Gas Atlas (Lockhorst 1997) shows that the thickness of the Rotliegend reaches over 2km. The basin stretches to the Russo-Polish border and has relatively thinner sands up to about 300m thick in the UK area. From a gas point of view this was a good reservoir; the seal was provided by the Zechstein Sea, which came in from the North Atlantic between Norway and Greenland (fig. 5.25 in Glennie 1998). Before the end of Rotliegend time the water probably had already reached the Shetlands, providing a little increase in moisture, and then finally it broke through into the southern basin to give not only carbonate reservoirs of variable quality but the salt which acts as a perfect seal. The coal underneath forms the source rock. The Carboniferous is overlain locally by a seal of desert lake sediments and it has its own reservoirs that can contain gas. The Rotliegend desert sediments round the edge of the lake has a top seal of Zechstein salt, making three nice little pancakes, one above the other, giving vertical migration for the entrapment of the gas - an ideal situation (Figure 3). There was a major hiatus that lasted up to 20Ma between the end of Coal Measure deposition and the start of the Rotliegend (Figure 4). There are some good younger reservoirs but it is difficult for the gas to migrate into them because the intervening Zechstein seal is so good; it is only where there is salt withdrawal (moving sideways to feed the diapirs) that the salt thins and fractures enough for gas to be released upward into the Bunter or younger rocks.

The giant Salzwedel field between East and West Germany contains over 60 trillion cubic feet of gas of which up to 95% is nitrogen, which meant that that field was almost uneconomic. A lot of nitrogen came as a result of deep burial associated with the volcanism that was concentrated in this area of the continent; it reaches between 80 and 100% nitrogen, whereas the UK areas contain 0 to 2% nitrogen.

Posidonia Shale is the source rock for oil in the Netherlands and Germany but is not mature in UK waters. In the northern North Sea the Kimmeridge Clay is the major source rock (Figure 5). There the Ekofisk field was discovered in Norwegian waters in 1969, then the major Forties Field in UK waters in 1970, and then in 1971 Brent was discovered, another 2 billion-barrel-sized oil field which confirmed the North Sea as a major oil producing area and started a mad rush to acquire acreage (Table 2 & Figure 6). The object was to drill as many wells as possible to prove whether there was oil or no oil in any particular block, because after six years 50% of the acreage had to be handed back to the government and the oil companies did not want to give up oil. So even dry wells were desirable for knowing what to hand back to the government.

To summarise: Brent started the Middle Jurassic play up in the northern North Sea, east of the Shetlands; Phillips, with Ekofisk, was in the Chalk; Forties became the Early Tertiary play; further south is the small Auk oil field, which reached down into Rotliegend and Zechstein reservoirs. The Frigg oil and gas field, discovered in 1971 on the Norwegian - UK boundary, is in the Eocene turbidites. Finally, in the 1990s there is the play west of the Shetlands; Foinaven and Shiehallion were discovered but we are still awaiting the full results. The latest UK discovery I've come across, in 1997, is the small Flora field close to the Danish-Norwegian median line area. These North Sea discoveries are summarized in Table 3.

Between 1969 and 1974 there were 25 discoveries giving a total of nearly $2x10^9m^3$ of proven recoverable oil plus gas in the UK sector. In the same time span the Norwegians discovered 15 fields with rather less oil. They have since caught up and overtaken us in terms of volumes of oil and gas discovered - especially oil.

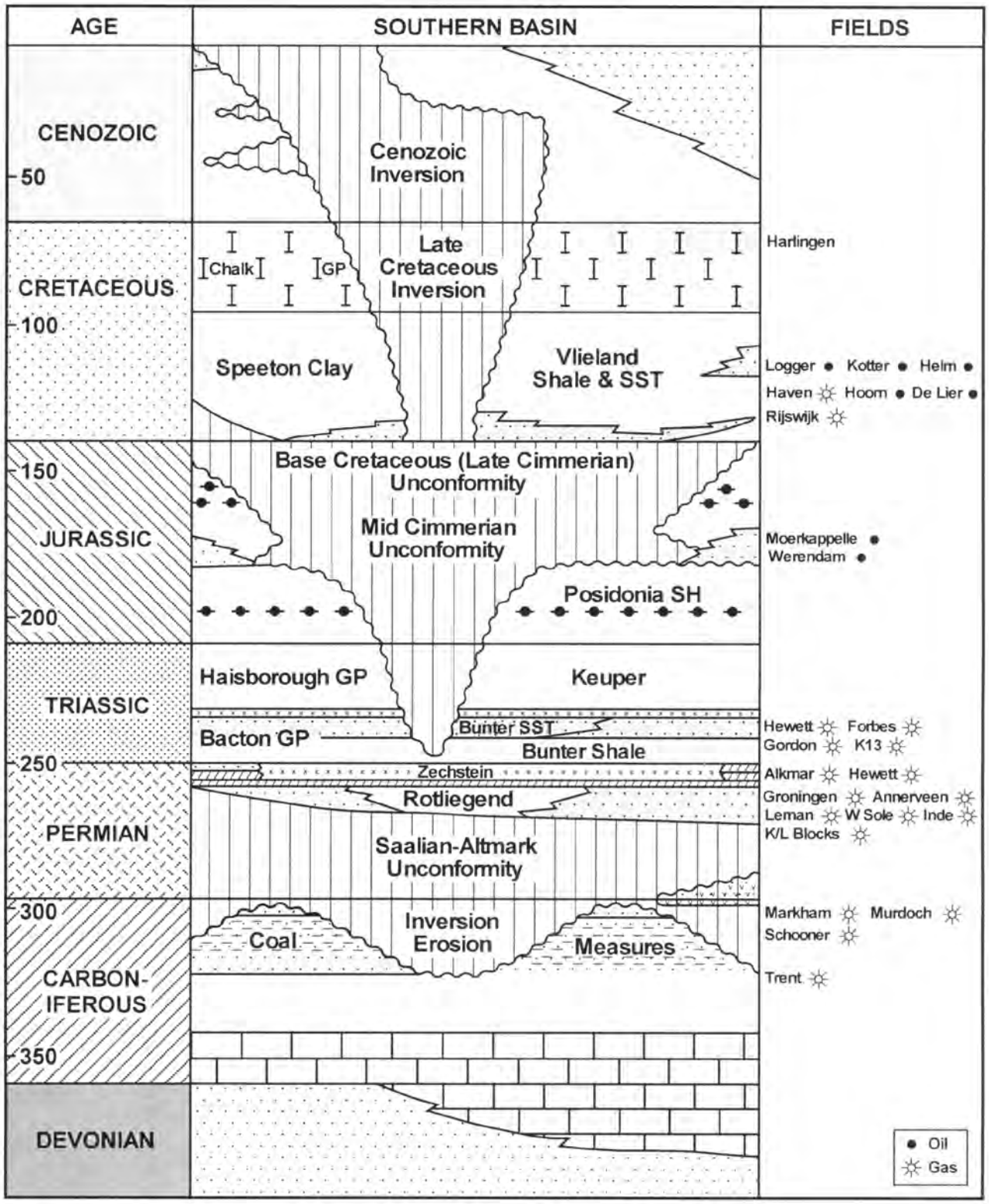

Figure 4. Simplified stratigraphy of the southern North Sea in the UK and Netherlands sectors, together with some of the important gas and oil fields.

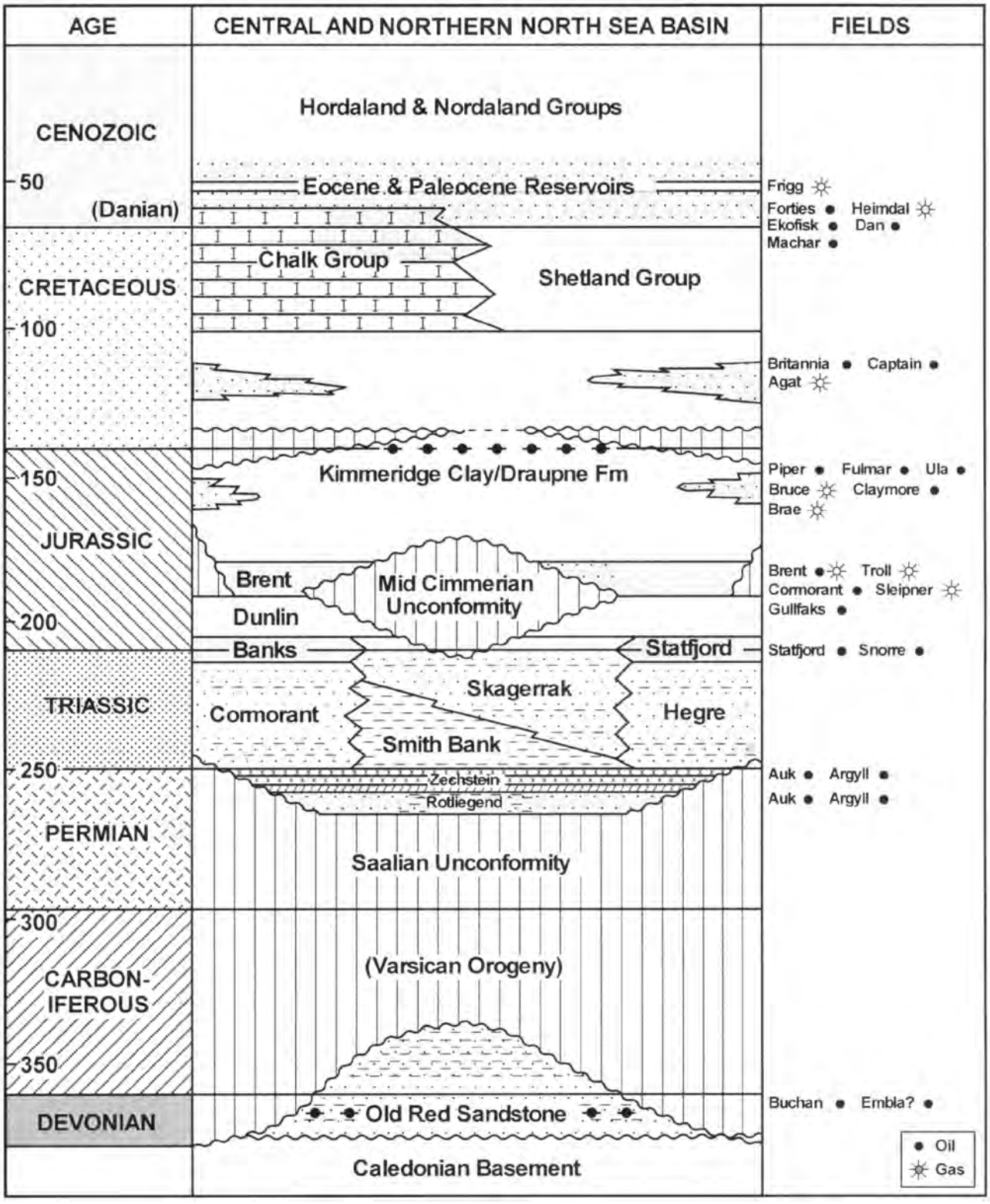

Figure 5. Simplified stratigraphy of the central and northern North Sea in the UK, Norwegian and Danish sectors, together with some of the important oil and gas fields.

ORDER OF DISCOVERY	FIELD NAME	DATE	OPERATOR	RESERVOIR	RESERVES o & c 10^6 m^3 g 10^9 m^3
1	Valhall	1967	Amoco	Ku	o 38 + g
2	Cod	June 1968	Phillips	Pc	g 8+c 3
3	Ekofisk	Dec 1969	Phillips	Ku/Da	o 237 + g 126
4	Tor	Nov 1970	Phillips	Ku/Da	o 18 + g 12
5	Ekofisk W	Dec 1970	Phillips	Ku/Da	c 10 + g 28
6	Eldfisk	Dec 1970	Phillips	Ku/Da	o 48 + g 39
7	Frigg (N + UK)	July 1971	Elf	Eo	g 191
8	Edda	Sept 1972	Phillips	Ku/Da	o 4 + g 2
9	Albuskjell	Oct 1972	Phillips	Ku/Da	c 8 + g 18
10	Heimdal	Dec 1972	Elf	Pc	g 36
11	Frigg O (a + b)	Sept 1973	Elf	Eo	g 13
12	Balder	May 1974	Esso	Pc	o 11-23
13	Statfjord	Dec 1974	Mobil	Jm/Jl/Tru	o 482 + g 88
14	Sleipner V	Dec 1974	Statoil	Jm	g 126 + c 45
15	Hod	Dec 1974	Amerada	Ku/Da	o 6
				TOTAL	**o+c 862, g 496**

Table 2a. The order, reservoir age and volumes of oil, condensate and gas in the 15 fields discovered in the Norwegian sector, 1969-1974. Pc Paleocene, Eo Eocene, Da Dananian, Ku Upper Cretaceous, Jm Middle Jurassic, Jl Lower Jurassic, Tru Upper Triassic, o oil, g gas, c condensate.

ORDER OF DISCOVERY	FIELD NAME	DATE	OPERATOR	RESERVOIR	RESERVES o 10^6 m^3, g 10^9 m^3
1	Gannet F	Mar. 1969	Shell/Esso	Pc	o 0.2
2	Arbroath	Dec 1969	Amoco	Pc	o 16
3	Forties	Nov 1970	BP	Pc	o 398
4	Auk	Feb 1971	Shell/Esso	Z/R	o 15
5	Brent	July 1971	Shell/Esso	Jm	o 359, g 159
6	Argyll	Aug 1971	Hamilton	Z/R	15
7	Lomond	May 1972	Amoco	T	g 13
8	Kingfisher	June 1972	Shell/Esso	J	o 9 + g 10
9	Beryl A	Sep 1972	Mobil Phillips	Ju/Tru Tru	o 127
10	Cormorant S	Sep 1972	Shell/Esso	Jm	o 100*
11	Deveron	Sep 1972	Britoil	Jm	o 3
12	Piper	Jan 1973	Elf	Ju	o 156
13	Maureen	Feb 1973	Phillips	Pc	o 33
14	Dunlin	July 1973	Shell/Esso	Jm	o 54
15	Thistle	July 1973	Britoil	J	o 64
16	Ellon	Aug 1973	Total	Jm	o 6
17	Dunbar	Nov 1973	Total	J/Tr	o 19
18	Hutton	Dec 1973	Conoco	Jm	o 28 +g 17
19	Heather	Dec 1973	Unocal	Jm	o 16
20	Osprey	Feb 1974	Shell/Esso	Jm	o 8
21	Ninian	Apr 1974	Chevron	Jm	o 162
22	Claymore	June 1974	Elf	Cl/Ju/Z/C	o 93**
23	Andrew	June 1974	Britoil	Pc/C	o 20+g 7
24	Bruce	July 1974	Hamilton	C/Jm/Jl	c 19
25	Magnus	July 1974	BP	Ju	o 102
				TOTAL	**o 1832 + g 193**

Table 2b. The order of discoveries UK Central and Northern North Sea 1969-1974. T Tertiary, Pc Paleocene, Eo Eocene, Ku Upper Cretaceous, Kl Lower Cretaceous, J Jurassic, Ju Upper Jurassic, Jm Middle Jurassic, Jl Lower Jurassic, Tru Upper Triassic,Tr Triassic, Z Zechstein, R Rotliegend, C Carboniferous, Cl Lower Carboniferous, o oil, g gas, c condensate. *Includes Cormorant

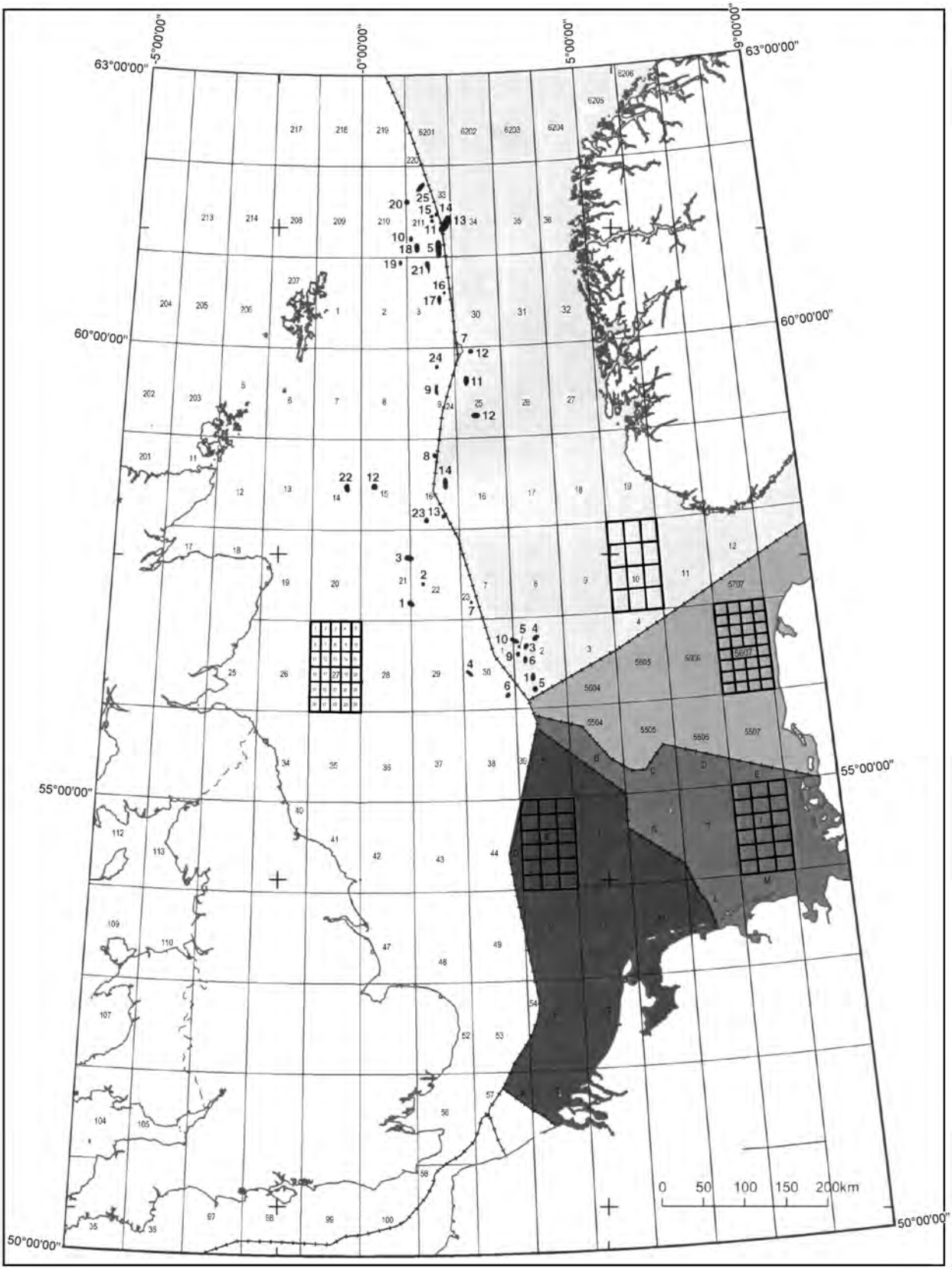

Figure 6. The order and distribution of discoveries in the separate UK and Norwegian sectors of the central and northern North Sea, 1969-1974. Note the differences in block sizes and numbering in each sector.

YEAR	NETHERLANDS	UK	NORWAY	DENMARK
1959	Slochteren-1			
1962	Annerveen (R, g)			
1963	Groningen			
1964				
1965		West Sole (R, g)		
1966		Leman, Inde, S. Viking (R, g) Hewett (B, g)		Kraka (Anne) (Ku, o + g)
1967		Big Dotty (R, g) Camelot N (R, g)	Valhall (Ku, o)	
1968	P6 (Z, Tr, g) L2 (B, g)	Caister (B, g) Rough, Deborah (R, g)	Cod (Pc, o)	Roar, Tyra (Ku, g)
1969	K7 (R, g) L12 (R, g)	Gordon (B, g) Montrose/Arbroath (Pc, o)	Ekofisk (Ku, o)	S. Arne (Ku, o)
1970	F18 (Ju, o) K7, K8, K11, K14 (R,g) L10, L13 (R, g)	Forties (Pc, o)	Tor (Ku, o) Ekofisk W (Du, o) Eldfisk (Ku, o)	
1971	K11 (R, o) L7, L11 (R, g) F3 (Ju, o)	Brent (Jm, 0) Auk (Z + R, o) Argyll (Z + R, o, abnd) [Kinsale Hd, IR] (Kl, g)	Frigg (Eo, g) Bream (Jm, o)	Dan (Ku, o/g) Gorm (Ku, g)
1972	L13 (B, g) K17 (R + Z, g) L4, L8 (R, o)	Beryl, (Ju/Tr, o)	Edda (Ku, o) Albuskjell (Ku, o) Heimdal (Pc, g)	
1973	K10 (R, g)	Piper (Ju, o)	Frigg O (Eo, g)	
1974	F3/2/6 (J, o)	Magnus (Ju, o)	Statfjord (Jm-l/Tru, o)	
	K4, K/15A (R, g) Rijn (K1, o)	Buchan (ORS, o) [Morcambe[(Tr, g)	Sleipner (Jm, g) Balder (Pc, o)	
1975	K15-FB (R, 25% CO_2)	Britannia (Kl, g/c)	Valhall (Ku, o)	Svend (Ku, ?)
		Scapa (Kl, o) Brae (Ju, o) Fulmar (Ju, o)		
1976	Q8 (R, g)	Beatrice (Jm, o) Machar (Da + Ku, o)	Ula (Ju, o)	
1977	L13 (R, g)	Captain (Kl, o) Clair (C/D, o)	Tommeliten (Ku, o + g)	Valdemar (Ku, o) Skjold (Ku, o)
1978		Gannet A (Pc, o) Clyde (Ju, o)	Gullfaks (Jm, o) Hild (Jm, o)	
1979	Haven (Kl, o + g) Helm (Kl, o) Helder (Kl, o)	Gannet B (Pc, o + g)	Oseberg (Jm, o) Snorre (Jl/Tr, o) Troll (Jm, g + o)	
1980	Hoorn (Kl, o) Kotter (Kl, o) K10-B2 (B, o)	Brae, E (Ju, o + g) Carnoustie (Z, o)	Agat (Kl, g) Brage (Ju/Jm, o + g)	Harald (Ku + Jm, g +o) Rolf (Ku + Z, o)
1981		Kittiwake (Ju, o) Emerald (Jm, o)	*Midgard (Jm, g/c) Askeladd, Jm, g)	
1982	Logger (Kl, o) Rijn (Kl, o)	Esmond (R, g) Everest (Pc, o + g)		
1983	J, K & L (c + g)	Miller (Ju, o) Vulcan (R, g)	*Tyrihans (Jm, g + c)	Dagmar (Ku/Z, o)
1984		Markham (C, g)	*Draugen (Ju, o)	Elly (Ku + Ju, o) Gert (Ju, o)
1985	Gl6 (?, g) K9c (R, g)	Murdoch (C, g)	*Heidrun (? o + g) Smorbuck (Jl/Jm, o + g)	
1986	K6 (g) F14 (J, o), F15 (?, g)	Schooner (C, g)	Albatross (Jl/Jm, g)	
1987		Gryphon (Pc, Eo, o)	Tordis (?)	
1988		Nelson (Pc, o) Shearwater (J, o + g)	Embla (D?, o)	
1989		Ganymede (R, g)		
1990		[Hamilton, Douglas] (Tr, o)	Trym (?)	
1991		Elgin (Ju, o + g)	Vale (?)	
1992		Foinaven (Pc, o) [Lennox] (Tr, o + g)		
1993		Schiehallion (Pc, o)		Siri (Pc, o)
1995				
1996				
1997		Flora (R, o)		

Table 3. Important post-Groningen oil and gas discoveries. Pc Paleocene, Eo Eocene, Ku Upper Cretaceous, Kl Lower Cretaceous, Ju Upper Jurassic, Jm Middle Jurassic, Jl Lower Jurassic, Tr Triassic, B Bunter, Z Zechstein, R Rotliegend, C Carboniferous, D Devonian, Da Danian, o oil, g gas [in Irish Sea] [IR Irish waters], *Atlantic continental shelf, Norway.

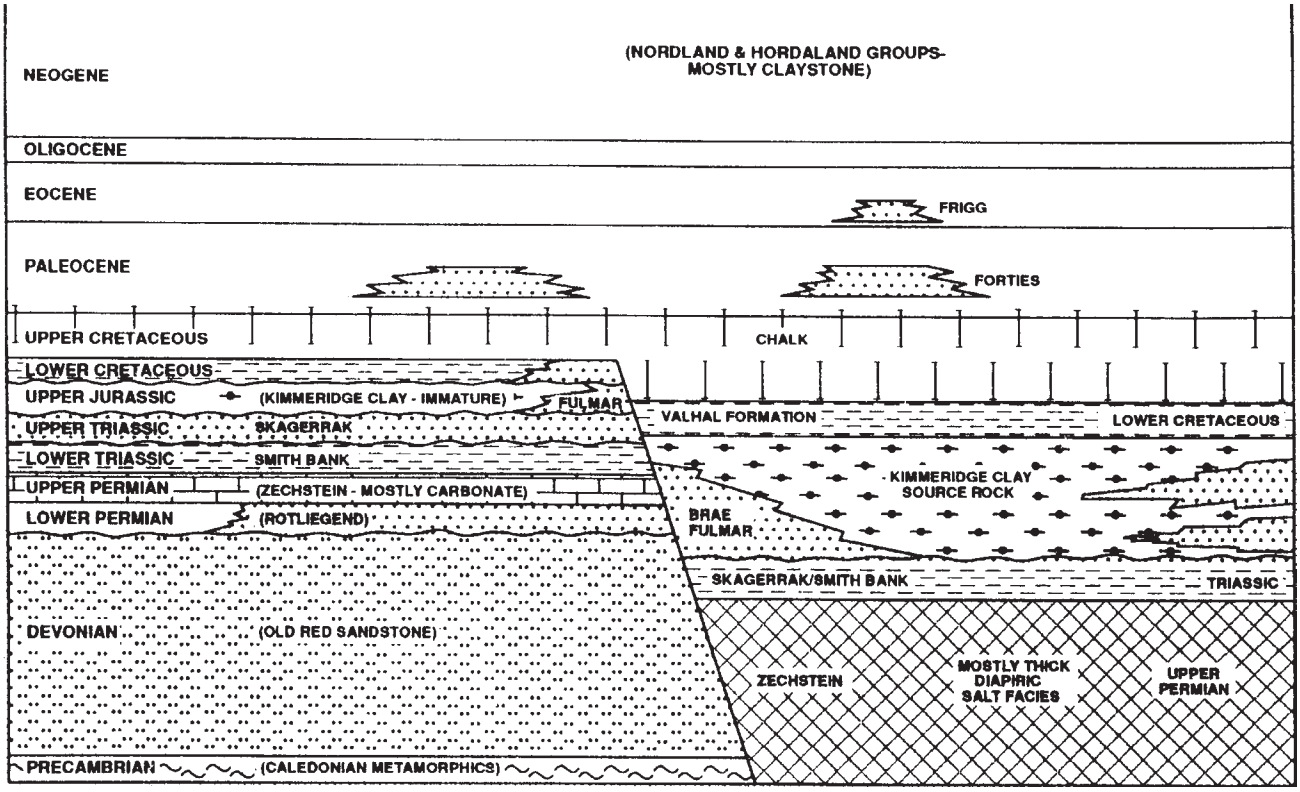

Figure 7. Source-rock/reservoir geometry: Central Graben and South Viking graben areas.

During exploration, a stratigraphic column (Figure 5) was revealed of the northern part of the North Sea. The oldest oil discovered was in Old Red Sandstone reservoirs - the Embla field has a Devonian reservoir; the Rotliegend and Zechstein reservoirs of the Auk and Argyll fields have the Cretaceous chalk acting as a top seal (see fig.5.38 in Glennie 1998b).

There is a major Mid Cimmerian unconformity in the middle of the northern North Sea caused by mid Jurassic volcanism, underlying heat and probably tension (Figure 5); the heat caused uplift of the rocks which eroded and then went down again as they cooled. Some of the products of erosion were important for providing the reservoirs in the Brent field in the northern North Sea. The major source rock is the Kimmeridge Clay, and Kimmeridge Clay oil has migrated to reservoir rocks as old as the Old Red Sandstone (Figure 7). Not only is the stratigraphy established, but a detailed structural map of the northern North Sea floor has been developed showing deep trenches and troughs separating 'highs'. The faulting is complex and follows a major, slightly NW/SE trend, coupled with a N/S component (fig.1.17 in Glennie 1998); all the result of differential plate tectonics acting over the continental area for a long period of geological time.

There had to be some way of getting the Kimmeridge oil from the source rock into reservoirs as old as Old Red Sandstone and as young as the Eocene Frigg sands. It is easy to understand vertically upwards migration along micro-cracks and fractures (e.g Figure 3), but in the graben area differential movement between the graben sediments, where the source rocks moved downwards and became mature relative to the flanking high areas, meant that oil could migrate laterally along faults into the Triassic Fulmar sands for example, which is a good shallow-marine reservoir rock (Figure 7). A play map (see fig.12.1 in Glennie 1998a) defines reservoir rocks of a particular age and geographical position in relation to mature source rock and a seal. In the south there is a broad belt of Rotliegend rocks stretching to the Russian border underlain by Carboniferous rocks which produce gas beneath the Rotliegend. In the graben area, Jurassic rocks of the Brent fields on the East Shetland Platform, the Brae field and many more in the southern Viking Graben form a Jurassic play. Then there is the little isolated Beatrice field where the source rock is a combination of Liassic (early Jurassic) source rock and underlying Old Red Sandstone (Devonian) lake sediments containing the Achanarras fish beds. The Irish Sea Morcambe Bay field is Triassic. On land and potentially off-shore is the essentially Triassic-Lower Jurassic Wytch Farm field, the biggest field we have on-shore in Britain.

Where did the oil and gas come from in the North Sea? 71% of all oil and gas can be attributed to Upper Jurassic Kimmeridge Clay source rock; 29% can be attributed to the Carboniferous source rock in terms of oil or oil equivalent; 0.005% from Liassic source rocks such as feed the Beatrice field - unimportant for the UK but important for the Netherlands (see fig.1.18 in Glennie 1998a). In the Netherlands on-shore gas of Carboniferous origin, the Groningen field has by far the biggest amount in on-shore reservoirs, but far less in off-shore fields. In the UK offshore there are more discoveries in the Permian, but far less in terms of barrel equivalent. Norway may now have a little more oil of Middle and Lower Jurassic age than the UK. Again for the Upper Jurassic, Norway has more. However, hydrocarbon-filled Tertiary Palaeogene turbidite reservior rocks are concentrated on the UK side of the median line rather than the Norwegian side.

Now, I mentioned that I'd show you, towards the end, some of the other slides that I received referring to the Slochteren / Groningen gas field. In Figure 1 you saw the Annerveen field on the left hand side of a hollow separating the Slochteren discovery from

what now turns out to be a much smaller field (Annerveen) - a field about the size of the Hewett gas field in the southern North Sea. Annerveen was discovered two years or so after Slochteren. The Slochteren well only just made it on the edge of the structure. But now I'm going to go northwards and see where that reservoir continues. We were just off the end of the map in the previous slide. When we carry on we've got more gas in Ten Post-1 and in Stedum-1. We eventually reach Uithuzen-1 up in the north, and we're beginning to get the gas-water contact within the reservoir about here. An enormous distance, 30km or so across, the area of the Groningen field is almost a thousand square kilometres and the column of gas where it fills the whole reservoir is about 180 metres - so it is an immense field.

When he was introducing me George Downie mentioned that I was interested in what happened to dune sands when they get flooded. Have any of you been up to the Hopeman outcrop area? I see some heads nodding - you will have seen deformation structures especially along the foreshore below some of the cliffs. Similar deformation structures appear in a series of cores from the discovery well for the Leman Bank field, 49/26-1(Glennie & Buller 1983). The Kupferschiefer, the base Zechstein, which also defines the top Rotliegend, is several feet above the top of the core sequence. Here, for instance, is a small fold, and there an escape structure; and there the sand is homogeneous and affected locally by pyrite cementation, with more deformation here. This display gives the Kupferschiefer at about 6000ft and is only a selection of cores. The start of undeformed Rotliegend dune sands is about 6118, i.e. 118ft of deformation of various types. As a result of the discovery of a mould of a fossil reptile just two years ago (Carol Hopkins), we now know that the Hopeman Sandstone is not Triassic, as much of the oil industry thought, sitting on top of a very poorly developed sandy shaley Zechstein, but is a basin-margin sandstone of the same age as the Zechstein itself.

That brings me to an end. Any awkward questions?

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Book review

Geology of Rum and the adjacent islands: Memoir for 1 : 50,000 Geological Sheet 60 (Scotland) by C H Emeleus, 1997, British Geological Survey, 170pp, £35.00 (paperback) ISBN 0 11 884517 9.

The small Inner Hebridean islands of Canna, Rum, Eigg and Muck lying to the south-west of Skye are off the main tourist routes in the West Highlands, though the area is outstandingly beautiful and of great interest to geologists. This is one of the Tertiary igneous districts of Scotland, and in the Small Isles, Palaeocene intrusive and effusive rocks form the majority of those exposed. The greater part of this Memoir is devoted to the detailed description and discussion of these lavas.

The Memoir, and the related 1 : 50,000 scale geological map, are the products of a mapping contract between the National Environment Research Council and the University of Durham; but its antecedents go back to 1908 when the original memoir was published. The author is Dr C H Emeleus of the University of Durham, whose research experience on Rum and the adjacent islands ranges over many years and his extensive knowledge of igneous rocks in general and layered intrusions in particular is complemented by contributions from other eminent geologists.

This is a superbly produced publication with magnificent, pin-sharp coloured plates and figures. The book is a joy to handle - and to read - and keen Open University Earth Scientists should find plenty to interest them in its pages. There are excellent accounts of pre-Palaeogene formations, of which the earliest is the Lewisian Complex consisting of feldspathic gneisses and amphibolites confined to Rum. Separated from these by an unconformity are Middle to Upper Proterozoic sandstones of the Torridon Group which in turn are separated by unconformities from Triassic and Jurassic sandstones. Above these, separated by yet another unconformity, are Upper Cretaceous limestones. The central interest of the Memoir relates to events in the Palaeocene in a region where crustal extension and fracturing has been taking place since the late Palaeozoic. Within a context of subsidence and crustal thinning, central intrusive complexes were established. Highly localised intense positive Bouguer anomalies prove that basaltic magmatism was dominant in the central volcanoes, but these alternate with silicic magmas, and there are also many large granitic intrusions.

The emplacement of the Rum Central Complex took place over 1Ma at 58Ma and consisted of an early episode when acid magmatism was dominant and closely linked with ring faulting. This first stage is characterised by caldera formation and the intrusion and effusion of silicic magmas. Stage 2 relates to the emplacement of the Rum Layered Suite of peridotitic and gabbroic rocks. These comprise the largest area of unserpentinised ultrabasic rocks in the British Isles. The account of these events is supported by detailed descriptions of the petrography and mineralogy with elegantly presented diagrams of the geochemistry. There is a particularly well-illustrated description of the Sgurr of Eigg Pitchstone Formation. This is a splendid work to which this brief report does only scant justice. It is a fine example of how a geological memoir should be presented, and reflects well on the author, the contributors and the British Geological Survey.

Angus Macpherson MA (Oxon) BSc (Open)

The Aberdeenshire Gabbros: a tale of two plutons

Sue Hay BA (Open), BSc, Ph.D. student at Royal Holloway, University of London

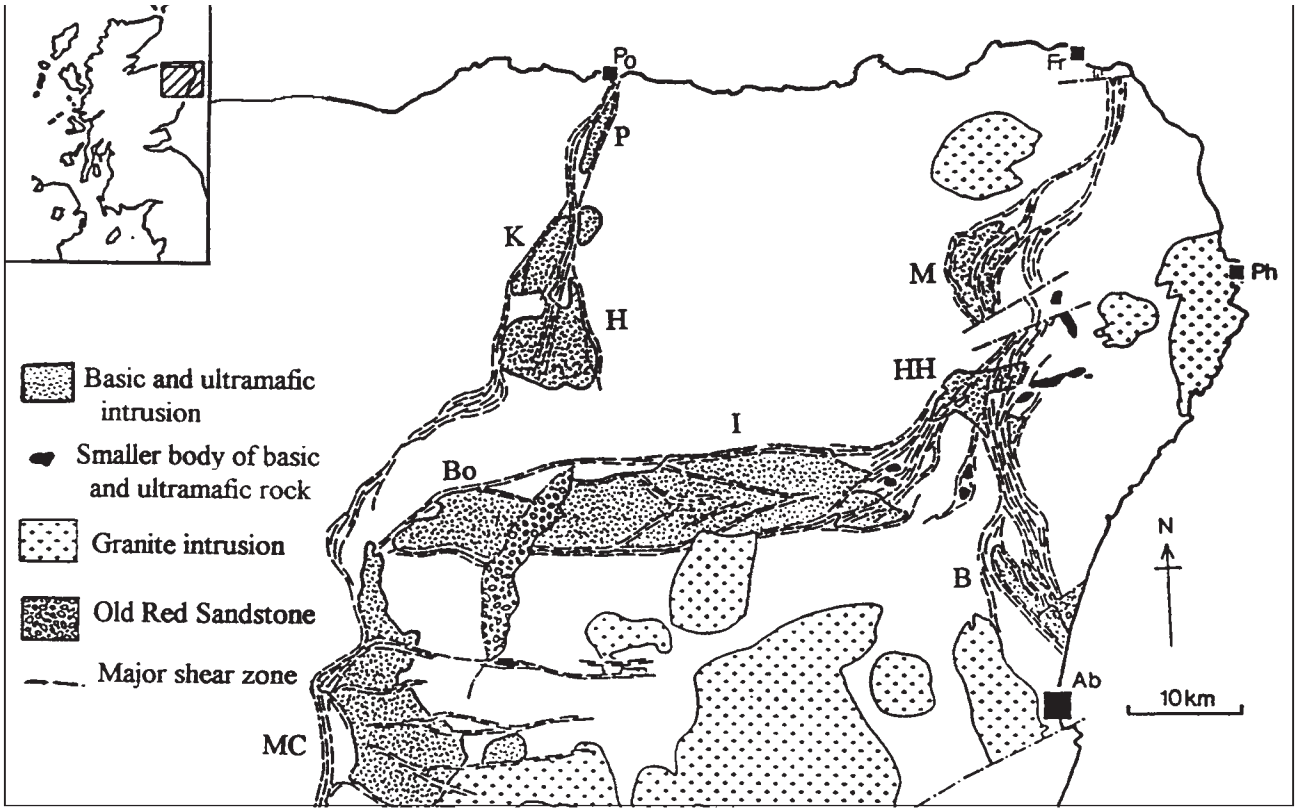

Figure 1. Geology of NE Scotland (after Ashcroft *et al.* 1984).
Towns: Ab - Aberdeen, Fr - Fraserburgh, Ph - Peterhead, Po - Portsoy
Intrusions: B - Belhelvie, Bo - Boganclogh, I - Insch, H - Huntly, HH - Haddo-House and Arnage, K - Knock, M - Maud, MC - Morven Cabrach, P - Portsoy.

Introduction

When most geologists think of Aberdeenshire and igneous rocks, it is granites that come to mind; however, there is also a large volume of basic igneous material (Figure 1). For the past few years I have been undertaking geochemical research, including detailed isotopic studies, on some of these intrusions. In this paper I hope to give you an insight into how such data is obtained and some of the results to date.

In 1919 Read distinguished two suites of gabbroic and ultramafic igneous rocks in the Grampian Highlands, an 'Older Basic' foliated and amphibolised suite and a 'Younger Basic' unfoliated suite. Because all of the Younger Basic intrusions are located within the county of Aberdeenshire, they are commonly referred to as the 'Aberdeenshire Gabbros'. More recent workers have shown that Read's criteria are not necessarily reliable in distinguishing the two suites, and some masses such as the Blackwater intrusion have been re-assigned to the Younger Basic suite (Fettes & Munro 1989). Stephenson & Gould (1995) in the latest British Geological Survey (BGS) Grampian Highlands Regional Guide proposed that all the Caledonian igneous rocks found in the Grampian Highland Region should be combined together into a 'Caledonian Igneous Suite'. They assigned many of the Older Basic rocks and all of the Younger Basic rocks to one division of this suite which they named Syn-to-Late-Tectonic Basic and Ultramafic Intrusions. They have defined this division as a suite of basic and ultramafic rocks intruded into the middle and upper Dalradian of the north-east Grampians during the D3 tectonic episode of the Caledonian orogeny, shortly after the peak of regional metamorphism.

The Aberdeenshire Gabbros are located in an area of intense deformation which has undergone high-temperature low-pressure 'Buchan' metamorphism (Fettes *et al.* 1986). The margins of these intrusions, which are very rarely seen, are tectonic and for the most part are coincident with large scale shear zones which commenced shearing shortly after the emplacement of the intrusions (Ashcroft *et al*. 1984). Movement on these shear zones has in places detached the metamorphic aureole rocks from the individual masses and displaced them by up to several kilometres. Shear zones have also developed within several of the intrusions.

The Aberdeenshire Gabbros

There are six major intrusions (Figure 1), some of which comprise 2-3 distinct masses separated from one another by Dalradian metasediments at the present level of erosion, and there are also several other smaller intrusions. The Insch pluton is the largest of the Aberdeenshire Gabbros; it is some 250km^2 in area and forms a 45km long east-west trending body if the Boganclogh intrusion, its probable extension, is included and is up to 8km wide. At this OUGS symposium Nigel Trewin confirmed that a borehole

Table 1. Cumulate mineralogy of the Aberdeenshire Gabbros.

Zone		Index minerals	Cumulate minerals	Rock types
Upper	c	ol-, opx-	ortho, plag, cpx	Syenite
	b	ortho+	plag, ortho, ol, cpx, opx	Monzonite
	a	ol+	plag, ol, cpx, opx	Olivine ferrogabbro
Middle		ol-	plag. cpx, opx	Gabbro Norite Anorthosite
Lower	c	cpx+, opx+	ol, plag, cpx, opx	Olivine gabbro
	b	plag+	ol, plag	Troctolite
	a	ol+	ol	Peridotite Dunite

ol - olivine, cpx - clinopyroxene, opx - orthopyroxene,
plag - plagioclase feldspar, ortho - orthoclase feldspar

through the Devonian sediments in the area between the two intrusions had terminated in altered gabbroic material. To the south-west of the Insch mass is the intrusion of Morven-Cabrach, a poorly known pluton whose southern end has been extensively altered by the later intrusion of the Ballater granite. Geomagnetic studies by BGS (Fettes *et al.* 1991) have shown that the Boganclogh and Morven-Cabrach plutons are in fact connected at depth. To the north of the Insch intrusion there is a group of three intrusions that are separate at the present level of erosion: Huntly, Knock and Portsoy. They extend some 26km north-south and underlie an area of some 100km^2. The largest and best exposed of the three plutons is the Huntly mass. The very poorly exposed Portsoy intrusion is the source of Portsoy Marble, a serpentinite that in the past was popular as a decorative stone. The intrusion nearest to the city of Aberdeen is the Belhelvie pluton, which is some 11km long onshore but is known to extend at least 5km offshore. The intrusions of Haddo House and Arnage which are situated between the Insch and Belhelvie masses are composed of basic magma which has been extensively contaminated by the partial melting of local Dalradian metasediments (Gribble & O'Hara 1967). Little is known about the sixth major pluton, Maud, due to its very poor exposure.

Cumulate rocks

The Aberdeenshire Gabbros are mainly composed of cumulate rocks. This term was first used to describe the rocks found in the Skaergaard intrusion, a superbly exposed Tertiary basic intrusion in south-east Greenland. The original paper on this intrusion by Wager & Deer (1939) is one of the most cited geological papers. Wager *et al*. (1960) proposed the term 'cumulate' as a group name for igneous rocks formed by crystal accumulation. This is a genetic definition, the underlying tenet being that the crystals accumulated by settling under gravity. In the late 1970s the concept of crystal settling was seriously questioned by Campbell (1978), McBirney & Noyes (1979) and others. One of the major objections was that plagioclase crystals, often the dominant cumulate mineral, are less dense than the melt and thus should float rather than settle. Campbell (*op. cit.*) suggested that *in situ* crystallisation might be more common than was then recognised. *In situ* crystallisation is now considered to play a dominant role in the formation of most large basic intrusions, although as Wilson (1989) has pointed out, this does not rule out the possibility of crystal settling occurring. Because of the uncertainties surrounding the actual mechanism(s) of cumulate formation, I prefer to use Irvine's (1982) definition of a cumulate rock, which describes the early crystallising components by textural criteria without implying the method of formation. Irvine (*op.cit.*) defined a cumulate rock as 'an igneous rock characterised by a framework of touching mineral crystals that were formed and concentrated primarily through fractional crystallisation'. Cumulate crystals are usually cemented together by texturally later postcumulus minerals. In general the cumulate crystals are bigger and have better crystal shapes than the postcumulus crystals which tend to be smaller and irregularly shaped; however, there are always exceptions to the rule.

Many large basic and ultramafic igneous bodies are divided into 3-4 main zones based on their cumulate mineralogy. The division that has been established for the Aberdeenshire Gabbros is shown in Table 1. The Lower Zone is defined by the presence of cumulate magnesium-rich olivine, initially on its own, forming a dunite. Slightly higher up the sequence, olivine is joined by cumulate plagioclase feldspar (forming troctolites and peridotites) and finally near the top of the Lower Zone by one or more pyroxenes to form olivine gabbros.

The base of the Middle Zone is defined by the absence of olivine as a cumulate mineral. The rocks of the Middle Zone are composed of cumulate plagioclase and/or pyroxene(s) forming gabbros, norites and anorthosites. The Middle Zone is also different from the other zones in the fact that non-cumulate rocks are present in the form of granular gabbros (some of which do contain olivine) and quartz-biotite norites. The relationship between the cumulate and non-cumulate rocks in this zone is often very complex.

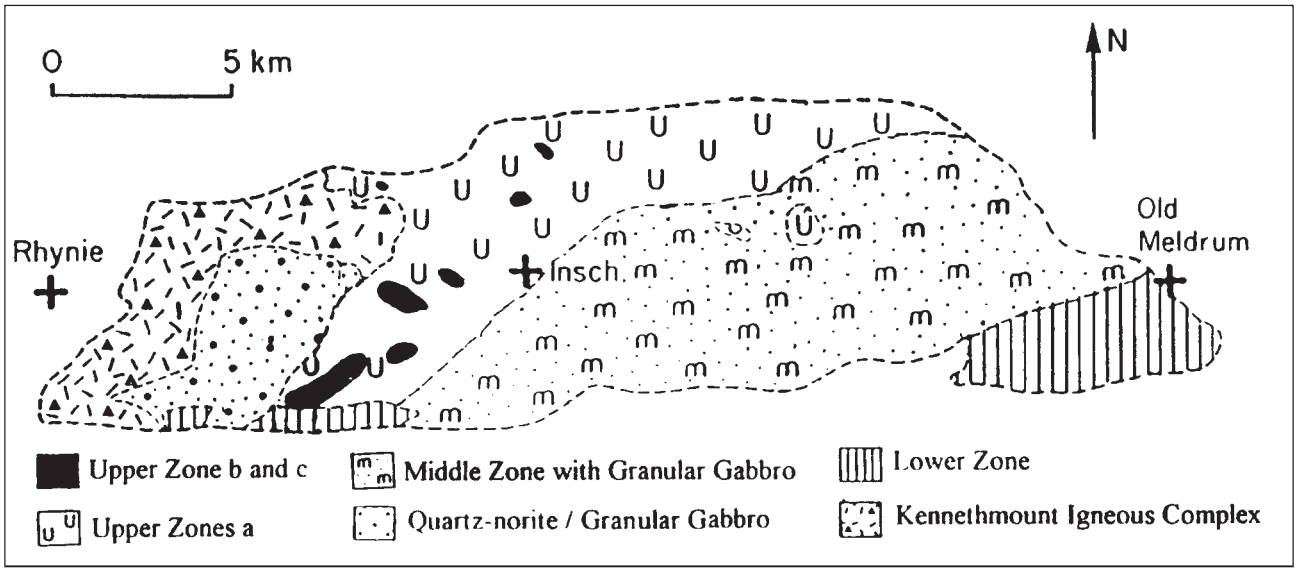

Figure 2. Geological sketch map of the Insch intrusion (after Clarke & Wadsworth 1970, Stephenson & Gould 1995).

The lower border of the Upper Zone is marked by the reappearance of cumulate iron-rich olivine. The alkali feldspar orthoclase also appears for the first time in Upper Zone b and gradually becomes the dominant cumulate feldspar. Final stage rocks are syenites composed of orthoclase, plagioclase and postcumulus quartz with less than 5% ferromagnesian minerals.

The Insch and Huntly intrusions

For the remainder of this paper I want to concentrate on just two of the Aberdeenshire gabbros: the Insch and Huntly plutons. Exposure in both intrusions is very poor, Insch being covered by arable or pastureland, whilst Huntly is largely covered by forestry. There is just one working quarry, in the Insch pluton, but there are also several old quarries in each pluton, the most notable being the Bin quarry at Huntly. Several of the smaller quarries, however, have been filled in over the last 30 years, considerably reducing the amount of outcrop. In spite of this, detailed petrological studies have been undertaken of each intrusion (Fletcher 1989; Clarke 1965; Wadsworth 1986, 1988).

All three main zones are present in the Insch intrusion (Figure 2), although there is only a small volume of Lower Zone rocks. The distribution of the cumulate rocks suggests that the intrusion is broadly synclinal in shape with its northward plunging axis running through the Upper Zone. Although its 3-dimensional shape is not clear, Clarke & Wadsworth (1970) speculated that the maximum thickness was approximately 5500m. Lower Zone rocks are very poorly exposed at the eastern end of the intrusion and also as pods of serpentinite, which are found along the southern margin of the intrusion. These probably represent Lower Zone cumulates which have been moved to structurally higher levels during shearing (Read 1956). The order of appearance of the cumulate minerals in the Insch intrusion is as follows: olivine-plagioclase feldspar-orthopyroxene-clinopyroxene; a similar order is also seen in the Belhelvie intrusion. Outcrops in the Middle Zone often show a complex relationship between several different rock types; the working quarry at Pitscurry is typical in that at least five different Middle Zone rock types can be seen. The relationship between the cumulate and non-cumulate rocks is also complex with no sign of either the cumulates or the granular rocks being chilled. There are indications that the non-cumulate rocks mainly intrude the cumulate rocks although there is at least one series of exposures where the non-cumulate rocks are intruded by the cumulate rocks. Upper Zone rocks are largely found outcropping on the sides of several small hills. There is no evidence of the actual roof of the intrusion but Wadsworth (1982) proposed that it was not very far above the highest Upper Zone rocks presently exposed. There is evidence of shearing at both the margins of the intrusion and within its interior.

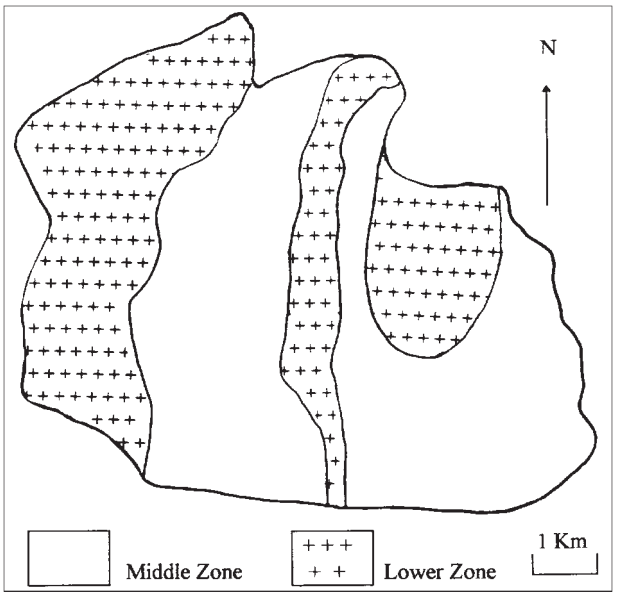

Figure 3. Geological sketch map of the Huntly intrusion (after Fletcher & Rice 1989).

The Huntly intrusion is composed of Lower and Middle Zone rocks (Figure 3). The base of the intrusion lies to the west, with steep to overturned primary igneous lamination seen at several locations, most notably in the Bin Quarry. There is, however, one small exposure, near the southern margin of the intrusion, which has some Upper Zone characteristics. If these are Upper Zone rocks then they are clearly not in their original position which suggests that the Upper Zone may have been removed by a combination of shearing and erosion. Fletcher & Rice (1989) sug-

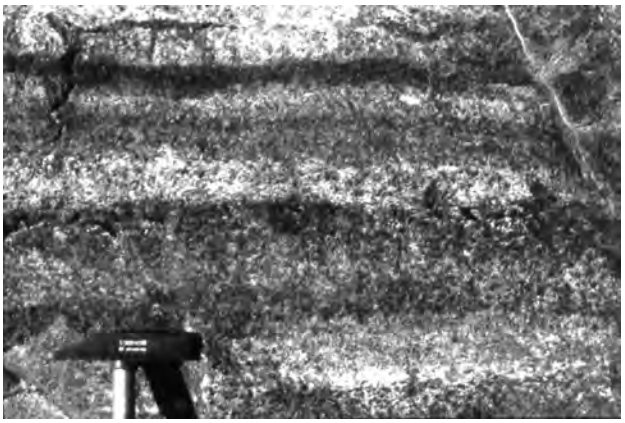

Figure 4. Layers of felsic and ferromagnesian minerals.

gested that the intrusion was some 3500m thick and composed of numerous concordant steeply dipping sheets up to 1km thick, striking approximately north-south. The two broadly similar sequences of rocks seen in the western and eastern parts of the intrusion are separated by a major north-south-striking shear zone.

There is a much larger volume of Lower Zone rocks compared to the Insch pluton and the order of the first appearance of the cumulate minerals is slightly different to that seen in the Insch mass with clinopyroxene appearing before orthopyroxene, the order being: olivine-plagioclase feldspar-clinopyroxene-orthopyroxene. Most of the Middle Zone rocks exposed in the Huntly pluton are non-cumulates, although some quartz-biotite norites have a cumulate texture. Rocks contaminated by Dalradian metasediments are particularly common near the eastern margin of the intrusion. Garnet and corderite are commonly found in these rocks together with xenoliths of Dalradian metasediments.

The cumulate rocks in both intrusions are generally medium to course grained and mostly homogeneous looking at outcrop, although in some areas layering can clearly be seen. These large basic intrusions are commonly called layered intrusions because layering is often well developed. This may be at all scales from the sheets as described by Fletcher & Rice (*op. cit.*) which are typically hundreds of metres thick down to millimetre-scale mineral layering. For example, in the Pitscurry Quarry at Insch feldspar-rich layers several metres thick are seen whilst in the Bin Quarry, near Huntly, centimetre-scale layering is clearly visible in the quarry face due to the concentration of felsic and ferromagnesian minerals in discrete horizons (Figure 4). Thin sections may also show layering, a few crystals wide, composed of alternating bands of feldspar-rich and ferromagnesian-rich horizons in which the minerals are all orientated parallel to the direction of the layering.

Major and trace elements

Solidification of magma involves either crystallisation or rapid freezing to glass. Crystallisation is a progressive process in which early formed crystals are followed by later-forming crystals i.e. fractional crystallisation occurs, there may be influxes of new magma and post-depositional processes are also likely to occur. So whilst the bulk composition of a lava may represent the liquid composition of the parental magma, this is not the case in large basic intrusions. Analysis of the major and trace elements, that in the case of a lava may give us direct evidence about the characteristics of the parental magma, in a large basic intrusion will tell us about the rocks' mineralogy rather than give any direct clues to the parental magma.

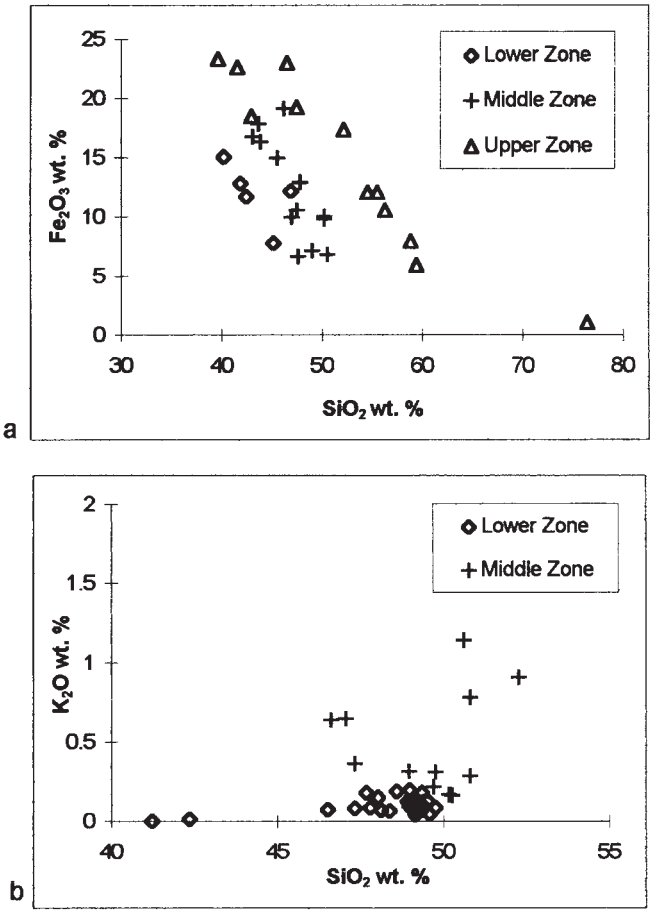

Figure 5. Harker variation diagrams: a) Total iron vs silica for the Insch intrusion; b) Potassium vs silica for the Huntly intrusion.

Harker variation diagrams of iron (Insch) and potassium (Huntly) against silica (SiO_2) are shown in Figures 5a and 5b respectively. In the case of Insch there is a negative correlation between silica and iron in each of the three main zones i.e. as the amount of silica increases the amount of iron decreases. This is particularly prominent in the Upper Zone, where Upper Zone *a* rocks are composed of plagioclase feldspar, iron-rich olivine and both pyroxenes with typically 55% plagioclase. Upper Zone *b* rocks typically contain over 60% feldspar (plagioclase and orthoclase) whilst Upper Zone *c* rocks contain less than 5% ferromagnesian minerals. This clearly shows the dominance of cumulate feldspar in this pluton. The rock with the highest silica content (76%) probably represents a final stage liquid and is composed of 70% alkali feldspar with 15% each of plagioclase feldspar and quartz.

Potassium is found in biotite with only very small amounts in olivines and pyroxenes. In the Huntly pluton most of the samples plot in a cluster (Figure 5b); the two Lower Zone ultramafic rocks which have the lowest SiO_2 concentrations contain at least 80% olivine, whilst the other samples which lie outside the cluster and have potassium concentrations greater than 0.5 wt. % are Middle Zone rocks, mainly quartz-biotite norites, containing at least 5% biotite.

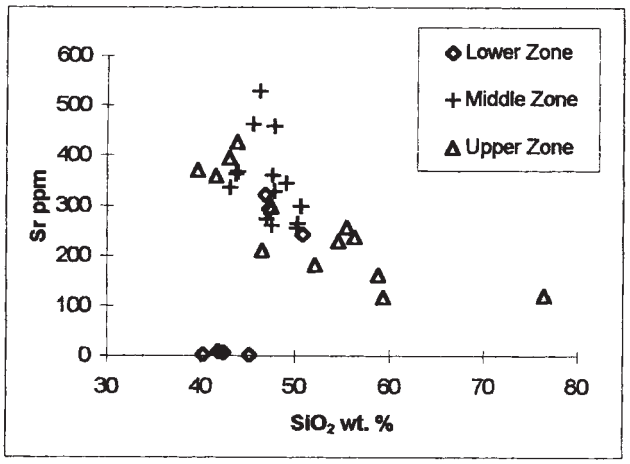

Figure 6. Harker variation diagram of strontium vs silica for the Insch intrusion.

The trace element strontium (Sr) substitutes for calcium and potassium; however, this does not mean that Sr is found in all minerals containing calcium and/or potassium. Sr tends to be concentrated in feldspars such as plagioclase and orthoclase and is only present in very small amounts in clinopyroxenes. A variation diagram of Sr against SiO_2 for the Insch intrusion (Figure 6) shows that the Lower Zone rocks plot in two distinct groups: the dunites which contain no feldspar have less than 10ppm Sr, whilst the olivine gabbros which contain about 40% plagioclase feldspar have some 300ppm Sr. You might expect the concentration of Sr in the Middle Zone rocks to be directly related to the amount of plagioclase present in the rock but this is not so, the very feldspar -rich rocks (70% plagioclase) in fact contain only some 350ppm Sr. Upper Zone rocks show a negative correlation of Sr with SiO_2 which at first glance is rather surprising as the total proportion of feldspars increases with increasing zonation. Substitution for calcium is thought to be the dominant process for the removal of Sr from a basic magma. With increasing zonation, however, the proportion of plagioclase (Ca-bearing) decreases and the proportion of alkali feldspar (K-bearing) increases.

Practical geochemistry

To be able to characterise the parental magma we need to look at the more incompatible elements such as the rare earth elements (REE) and the radiogenic isotopes strontium and neodymium (Nd). In the past, speakers at OUGS symposia have shown REE and isotope diagrams but I have never heard anyone explain how they obtained their results. A lot of hard preparation is involved particularly if mineral separates are to be analysed. Initially all the weathered material has to be removed from each rock sample, which is then crushed and ground to a fine powder if the whole rock contents are to be analysed. These powders are also used for determining the major and trace element contents by X-ray fluoroscopy (some of whose results were discussed in the previous section). If mineral separates are required then the rock is ground to about the grain size of a fine sand, depending upon the size of the mineral crystals to be separated. Each sample is then passed, often several times, through an electro-magnetic separator which will separate the ferromagnesian minerals (e.g. olivine and pyroxenes) from minerals such as feldspars. Whilst the feldspar fraction will now be quite pure, the ferromagnesian fraction is often a mixture of olivine and two pyroxenes. Liquids of known densities can be used to separate the pyroxenes from the other ferromagnesian minerals by allowing one fraction to sink whilst the other floats. It is difficult, however, to separate clinopyroxene from orthopyroxene by this method because their densities are so similar. Finally, the feldspar-rich and pyroxene-rich fractions are sorted by hand to obtain pure samples of each mineral. This is achieved using a binocular viewer and a pair of tweezers. Although only about 0.5g of each separate is required, on average I can only expect to obtain about 0.01 - 0.02g per two hour session (about as long as your eyes will stand at any one time). Over 20 mineral separates were eventually required for this research.

Once obtained, the samples are dissolved completely in acids such as hydrofluoric and nitric. The dissolved sample is then passed through an appropriate ion exchange column where the desired element is separated from the rest of the sample. In the case of Sr the sample is only passed through one set of columns (in batches of six samples) the whole process taking under 24 hours including the time needed to clean the columns (to prevent contamination) before the next user. REE and Nd samples have to be passed through two and three different sets of ion exchange columns respectively and in the case of the Nd samples they are in fact passed through the second set of columns twice, each pass taking about 48 hours including column cleaning.

Each sample is then loaded onto a filament that looks a bit like a light bulb filament and placed in the mass spectrometer. A mass spectrometer is an instrument designed to separate charged atoms on the basis of their motions in an electro-magnetic field. So elements that have more than one isotope can be determined by this method. The mass spectrometer that I have been using can take up to 16 samples at a time and, dependent upon the element(s) being analysed, takes about 36 - 48 hours to run each batch of samples. Liquid nitrogen is used to obtain a really good vacuum (order of 10^{-7} atmospheres). The samples are heated by passing a current through the filament sufficient to vaporise and ionise the element to be identified. The ions then pass down a long narrow tube which has a curved path through an electro-magnet. Each isotope, having a slightly different mass, will be deflected through a slightly different angle by the electro-magnet so it can then be collected separately and the proportion of various isotopes or the absolute amount of a particular REE can be calculated.

Rare Earth Elements

REEs are amongst some of the least compatible of the trace elements i.e. they are more likely to stay in the magma than be incorporated in the lattice of a crystallising mineral. The REE pattern of an igneous rock is controlled by the REE composition of the source and the crystal-melt equilibria. To be able to compare one pluton with another, the abundances of REEs in each pluton are normalised against chondritic abundance and plotted in order of increasing atomic number. Normalising the REE abundances helps to bring out the degree of fractionation the magma has undergone compared with primordial distribution patterns and also smoothes out the odd-even zig-zag pattern of absolute REE abundances, which makes interpretation of the REE patterns easier.

REE diagrams of representative samples from the Insch and Huntly intrusions are plotted in Figures 7a and 7b respectively. In both plutons there is an increase in REE abundance with upward zonation; Lower Zone Rocks (I1009, H204 and H219) contain some 1-10 times chondritic abundance, whilst Middle Zone samples (I120, I30, I125 and H213) have about 10 times chondritic

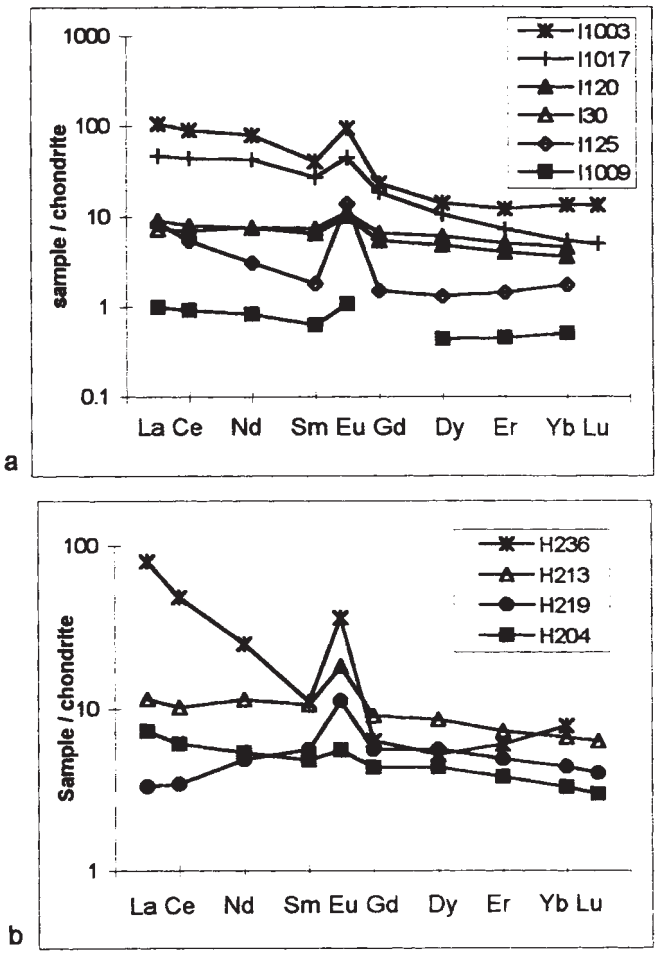

Figure 7. Chondrite-normalised Rare Earth patterns: a) Insch intrusion; b) Huntly intrusion.

abundance and Upper Zone samples (I1017 and I1003) have nearly 100 times chondritic abundance. As REEs are incompatible elements, any suite of rocks related by fractional crystallisation would be expected to have a positive correlation between increasing differentiation and chondrite-normalised abundances. With one exception (H219) all the samples are enriched in light REEs compared to the heavy REEs, which suggests that the heavy REEs may have preferentially remained in the mantle source area, in minerals such as garnet.

There is a positive europium (Eu) anomaly in all the samples which increases with upward zonation. Europium is unique amongst the REEs in being stable in the divalent state. It has an ionic radius close to that of Sr and so becomes preferentially concentrated in Sr-bearing minerals such as plagioclase feldspar. The Insch Lower Zone sample (I1009) in which gadolinium (Gd) failed to run illustrates the problem of trying to analyse samples which contain very low REE concentrations. All the REEs concentrations obtained for this sample were less than 0.1ppm. At first glance the Lower Zone samples from Insch (I1009) and Huntly (H204) appear to be different; whilst having similar REE patterns, they have very different REE concentrations (by a factor of about 10). The Insch Lower Zone sample is a dunite and the Huntly sample is an olivine gabbro. The partition coefficients for REEs in plagioclase and pyroxenes are some 10-100 times higher than those for olivine; thus more REE will enter the plagioclase and pyroxene lattices than olivine, hence the difference in concentrations between the two samples. Sample H219 has a different REE pattern to the other Lower Zone rocks with lower concentrations of the lightest REEs e.g. Lanthanum (La) and Cerium (Ce). This rock is located in the middle of a major shear zone and has most probably been altered during shearing.

Major element analysis has indicated that the non-cumulate Middle Zone rocks are geochemically very similar to the cumulate Middle Zone rocks and the REE patterns confirm this similarity (sample I120 is a Middle Zone cumulate rock, whilst samples I30 and H213 are Middle Zone non-cumulates); however, sample I125 (a granular non-cumulate gabbro) has a different REE pattern. Sample H236, which has a similar REE pattern to I125, is known to be contaminated by Dalradian metasediments, so it is likely that I125 may be likewise contaminated. This was not obvious from the major and trace element data but is confirmed by a high Sr isotopic ratio for I125, which is also suggestive of crustal contamination.

Radiogenic isotopes

Isotopic ratios of rocks allow us to set important constraints on the interpretation of magma chamber processes. This is because the isotopic ratios of heavy elements such as Sr and Nd are not changed during fractional crystallisation and, in principle, only vary by mixing between end-members of contrasting isotopic compositions such as during crustal assimilation and magma-mixing. Such processes have been identified in several large layered intrusions by isotopic studies. Radiogenic isotopes, particularly Nd, can also be used to obtain accurate ages for large basic plutons.

When dating lavas it is possible to construct an isochron from a co-magmatic suite of lavas from which the age of the rocks can then be calculated. In rocks where fractional crystallisation has occurred this is not possible, so isochrons are constructed by analysing some of the co-existing minerals in a sample. For each sample from the Insch and Huntly intrusions a whole rock plagioclase and clinopyroxene separate was used. Some of the dates obtained are shown in Table 2. Although at first glance these dates would appear to suggest that the Huntly pluton is slightly older than the Insch mass, when the errors are taken into consideration and further isochrons have been constructed it may well be that both plutons will have a similar age of around 470 Ma.

Table 2. Sm-Nd ages obtained for the Insch and Huntley intrusions.

Sample	Calculated age (Ma)
I119	451 ± 28
I127	450 ± 17
H213	474 ± 12
H219	467 ± 15

A basic, uncontaminated magma of mantle origin would be expected to have Sr ratio ($^{87}Sr/^{86}Sr$) values in the range 0.702-0.704. The ultramafic Lower Zone rocks of both intrusions should be the least differentiated and thus have the lowest Sr ratios. This is true for the Huntly intrusion, where all the Lower Zone rocks have Sr ratios of approximately 0.704. In the Insch pluton, how-

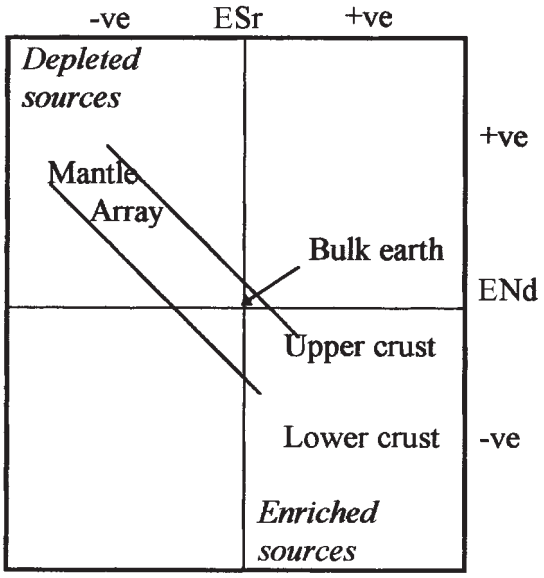

Figure 8. Epsilon diagram for Sr and Nd isotopes.

ever, it is different: Lower Zone rocks have a wide range of Sr ratios (0.706-0.711) all of which indicate extensive crustal contamination has probably occurred. The two lowest Sr values come from two of the granular non-cumulate gabbros (both 0.703). Further analysis of these two samples, particularly Nd isotopes and REEs, may give information about the characteristics of the magma source.

Some previous workers have suggested that a pulse of new magma influxed at the base of the Upper Zone. If this did occur then we would expect to see a lowering of the Sr ratio, which does not seem to be the case; the uppermost Middle Zone rocks and lowermost Upper Zone rocks have very similar Sr ratios of around 0.711. There is a difference, however, between the highest Lower Zone samples and lowest Middle Zone samples (Lower Zone samples 0.711; Middle Zone samples 0.704). Analysis of Sr ratios against stratigraphic height within each of the plutons may help to clarify this and other outstanding issues.

Epsilon diagrams

A more flexible way of diagrammatically showing the Sr and Nd isotopic ratios of rocks, which are the same age, is the epsilon diagram. Epsilon (E) values are a measure of deviation of the sample from the value found in a uniform reservoir (commonly known as 'Bulk Earth') of the same age. As shown in Figure 8, magma sources depleted compared with 'bulk earth' have negative ESr values and positive ENd values, whilst sources enriched compared with 'bulk earth', such as the crust, have positive ESr values and negative ENd values. The so-called 'mantle array' is the source of many oceanic basalts including MORB.

An epsilon diagram for samples from the Insch and Huntly intrusions together with some lower Dalradian rocks (Figure 9) shows that the Insch and Huntly samples all plot between the end of the mantle array and the crust. This suggests that the parental magma had a depleted mantle origin which was subsequently contaminated by crustal material during its ascent and eventual emplacement in the upper crust at about the climax of the Caledonian orogeny some 470Ma ago.

I hope that this paper has shown that geochemical techniques,

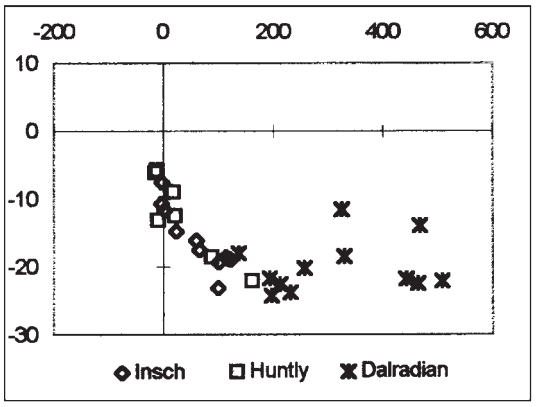

Figure 9. Sr and Nd epsilon diagram for the Insch and Huntly intrusions.

although time-consuming, can give an insight into the origin and the history of large basic and ultramafic intrusions such as the Aberdeenshire Gabbros, which in turn will add to our knowledge of the Caledonian orogeny within the Grampian Highlands.

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Book reviews

The Tectonic Evolution of Asia, by A Yin & M Harrison, 1996, Cambridge University Press, 660pp, £125.00 (hardback) ISBN 0521480493.

Although the book's appearance may well instil fear into the average non-specialist reader, appearances can be deceptive. The contents are separated into five parts, each dealing with a specific area of the tectonic evolution of Asia. Each part is further divided into subsections, making easy access to a particular area of interest for the reader. I particularly liked the way each subsection had an abstract, introduction, main body of text and conclusion.

The first part of the book on geodynamic models was heavy going, not being comfortable with the equations I found myself floundering a bit, but managed to get the basic gist. Once I had got into the next part on seismotectonics, the earthquake history and faulting of Asia, I was particularly enjoying the book. The third part on the geologic evolution of the Himalaya-Karakorum range would be of particular interest to students who have studied or are studying the third level hard rock course. The material in this section obviously goes into much more depth and detail, but it was interesting to get a better insight into this area after the appetite was whetted on the course.

Part four of the book dealt with the tectonics of the Cenozoic Indo-Asian collision and referred to the high plateaus, mountain ranges, basins and shear zones and major faults of Central and Eastern Asia. The final and largest part, over half the book, dealt with the Mesozoic-Paleozoic assembly of Asia. A thoroughly fascinating insight that could have been published as a separate book in its own right.

There are 21 contributions to the book, but I felt that this did not distract in any way to the structure and flow of the contents. I would say even for the graduates amongst us it is not the sort of book one can read from cover to cover and is best dipped into when looking at a particular area of interest. The text is well supported with good diagrams, satellite images, maps, tables and photographs. I think students of the third level hard rock course would find it particularly interesting although it is an expensive book to purchase.

Sandra Murray BSc Hons (Open)

Agate Microstructure/Origin by Terry Moxon, 1996, Terra Publications, 106pp, £6.90 (paperback) ISBN 0952851202.

This is a very useful book for anyone interested in agate. It ranges over where to find agate, what it is, how to make equipment to look at it closely, texture, colours, banding, and historical discussions on agate genesis. The detail is such that the book is happily informative for both the amateur, such as myself, and, as the last detailed review in English was as long ago as 1927, to the serious collector as well. Much of the information has been translated from German texts, added to the author's personal knowledge of agate over twenty years of interest in the field and the results are well worth reading. The Midland Valley of Scotland is the major source of agate in the UK and the first chapter describes the area, its formation and the sites and explains why it is difficult now to find specimens in classic sites. This is a problem in other areas of collecting, of course. He does say that it depends on what your requirements are. Beautiful perfect specimens are rare indeed but for those interested in research there is ample evidence to be found.

Thin section techniques occupy a full chapter and make quite fascinating reading for anyone interested in doing their own thing rather than investing in expensive machinery. I find a lot of impecunious geologists are very inventive when it comes to money saving equipment and this chapter backs that to the hilt. The next four chapters deal in detail with microstructure, colour, banding and crystallisation of agates. I am only a beginner at minerals and I am very dim on chemistry but I found the text easy to read and I understood most of it. I suppose the fact that I am also interested in flints must have helped a little.

Agate genesis occupies the final two chapters and here again the information is clearly displayed. The photographs of various sorts are all black and white and, though I longed for the beautiful colours of this mineral, show clearly the patterns of its formations. The book would also fit into a storm jacket pocket which has to be a plus and would make a sufficiently interesting read to take one's mind off unpalatable facts if marooned on a wild Scottish hillside while searching for these beautiful stones. I intend having a copy of this.

Doreen Smith BSc and continuing Earth Science student

Groundwater, our hidden asset by R A Downing, 1998, BGS Earthwise, 61pp, £6.50 (paperback) ISBN0852723040.

This publication is a neat paperback booklet written at two levels of understanding. The text in black forms the general account for the lay person and can be read as continuous text. Supplementary details of important issues, together with reviews and case studies, are provided alongside in blue text for those requiring in-depth information.

The information is presented under twenty main headings and begins by discussing what groundwater is, then looks at its uses and the distribution of aquifers in the United Kingdom. Groundwater flow, quality and chemical composition together with the development of groundwater resources is considered.

The vulnerability of aquifers to contamination by a variety of substances including pesticides, nitrates, industrial chemicals, urban pollution and intrusion of sea water in coastal regions is discussed together with some possible remedies.

An abundance of clearly labelled diagrams, maps and photographs, all in colour, complement the text. This booklet would be of interest to people from a wide variety of backgrounds, both scientific and non-scientific. The cover price of £6.50 is very reasonable.

Elizabeth Martin BSc Hons (Open)

Palaeoecology of Old Red Sandstone Fish Beds of Scotland

Dr Nigel H Trewin, University of Aberdeen

Introduction

The Old Red Sandstone of Scotland is famed for the spectacular fish fossils that were brought to world attention through the work of Hugh Miller (The Old Red Sandstone 1841) and the monographic work of Agassiz (1844). The earliest Scottish fish faunas occur in the Silurian inliers of the Midland Valley and were dominated by agnathans (jawless fish). These fish lived in basins of variable salinity, which became isolated from the oceans with the closure of the Iapetus Ocean. Fish appear to have rapidly colonised fresh water environments in the Silurian and Early Devonian, and there is virtually no evidence for marine influence in any of the classic Old Red Sandstone fish beds of Scotland.

Whilst the majority of the Old Red Sandstone (ORS) is of Devonian age, it must be noted that ORS facies extend back into the Silurian with the Stonehaven Beds, containing the 'Cowie Harbour fish bed', now being regarded as Wenlock in age (Marshall 1991). At the top, the Upper ORS passes conformably into Carboniferous marine strata, and parts of the Upper ORS are of Early Carboniferous age.

My intention is to review a few of the classic ORS fish localities in Scotland and provide an impression of the faunas, their life environments, and reasons for their preservation. In many cases the fish did not live in the environment in which they were preserved, and ecological conclusions are consequently speculative!

Lower ORS - Midland Valley

The Lower ORS of the eastern Midland Valley is the most important area in the world for well-preserved Early Devonian acanthodian (spiny-finned) fish. A number of fish beds are present, the best known being in the Turin Hill area, with the disused Tillywhandland Quarry being the only remaining easily accessible site (SSSI, permit required).

Recent detailed survey of the quarry and its fauna and flora (Trewin & Davidson 1996) has shown that the fish are virtually confined to 50cm of green-grey laminated shale and siltstone. These rocks are 'lacustrine laminites' and comprise regular sequences of laminae on a mm scale which comprise clastic, carbonate and organic laminae which have been interpreted as the deposits of a eutrophic lake under the influence of a seasonal climate (Rayner 1963, Trewin 1986). The lake waters were seasonally thermally stratified and the bottom waters poor in oxygen, but rare bioturbation shows that conditions were not permanently anoxic.

A fascinating feature is that the laminites of the fish bed overlie a coarse fluvial channel sandstone, and veins of sandstone have been injected upwards into the fish bed. The evidence suggests that the lake body was established very rapidly, maybe as a consequence of volcanic activity or faulting (Trewin & Davidson 1996). Sedimentation in Lake Forfar was initially slow and comprised the laminites of the fish bed. As time passed, maybe 1000 years, the lake gradually filled as rivers dumped their load into the lake. The fish bed grades up into thin graded siltstones followed by sandstones with ripples and drifted plant debris; the water shallowed and alluvial conditions were re-established.

The fish fauna is dominated by the acanthodians *Mesacanthus* and *Ischnacanthus*. *Mesacanthus* was probably a small shoal fish, and a group of six has been found in a single small slab of green shale, probably suffocated in a sediment cloud. However, most fish are isolated in the laminites, and appear to have drifted to the site of deposition after death. Decomposition took place during transport, so some specimens are missing the skull or jaws that fell off the carcass early in the decomposition process.

Ischnacanthus had strong jaws with teeth and was clearly a predator. Coprolites are common in the fish bed, and they contain scales and spines of *Mesacanthus* and small *Ischnacanthus*. *Ischnacanthus* probably preyed on *Mesacanthus* and young of its own kind. Other fish are rare and include *Climatius*, *Parexus* and *Euthacanthus*. There was clearly a varied fauna of acanthodians, which are accompanied in the fish bed by a cephalaspid (*Zenaspis*), of which isolated headshields are most frequent. Other fauna comprises arthropods; with eurypterids represented by *Pterygotus* and others. Of greater rarity are millipedes that had a terrestrial habitat and must have drifted out into the lake before drowning and sinking. A general cartoon of the environment is shown in Figure 1.

In the Lower ORS finds of large complete *Pterygotus* and complete cephalaspids are usually associated with fluvial sandstones, and they may have preferred fluvial channels rather than the lakes. The land was clothed with plants in low-lying wet areas, with *Zosterophyllum* and the enigmatic *Parka* being most frequently found at Tillywhandland.

Middle ORS - The Achanarras Fauna

Passing up into the Middle ORS, the Achanarras fish bed at Achanarras Quarry in Caithness (SSSI) has yielded the most diverse fish fauna of any of the ORS fish beds. Fourteen well-known genera and a few organisms of uncertain affinities have been found (Trewin 1986).

The fish at Achanarras are also found in laminites deposited in a deep lake (Hamilton and Trewin 1988), but it appears that they all drifted to the site of deposition, and represent the product of mass mortalities in the Orcadian Lake (Figure 2). Counting the laminites indicates that the 2m thickness of the fish bed represents some 4000 years of deposition, and changes in the relative abundance of the fauna are apparent during this time period. As far as palaeoecology is concerned, we can only deduce the likely modes of life of individual fish. There is little evidence to suggest how they interacted in a community structure.

Glyptolepis, frequently over 50cm long and equipped with strong teeth, was clearly the top predator, and one specimen is known in which a *Glyptolepis* died trying to swallow one of its own kind. *Coccosteus* was also a predator and bones and scales of other fish are occasionally found in its stomach contents. The lung fish *Dipterus* was probably omnivorous, and also tolerant of adverse (? Low O_2) conditions since it is the first fish to appear at the base of the bed and the last to die out. Shoals of small acanthodians (*Mesacanthus*) are associated with *Palaeospondylus*. The central part of the fish bed contains the greatest fish diversity, probably

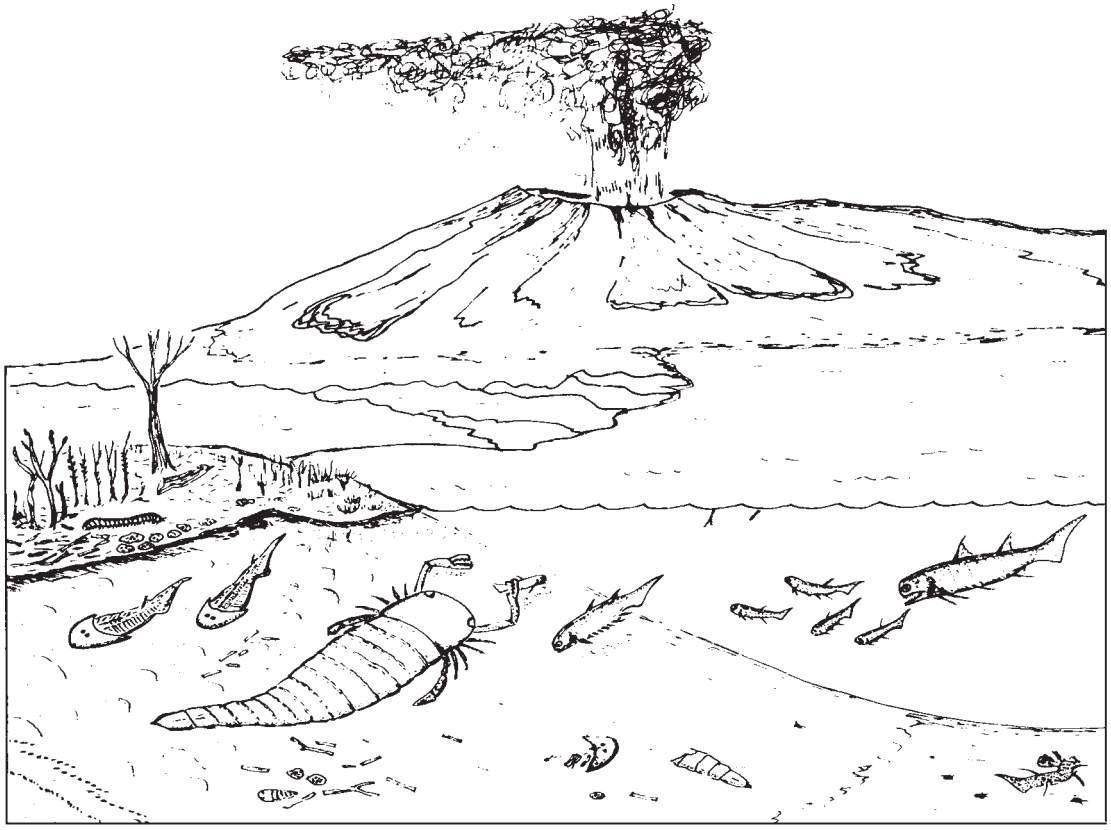

Figure 1. Cartoon, not to scale, of the margins of Lake Forfar in the early Devonian. Plants (*Zosterophyllum, Parka*), millipedes and other arthropods known only from trace fossils occupied the land. *Pterygotus* and cephalaspids (*Zenaspis*) existed as vagrant benthos in shallow sandy areas. Acanthodian fish occupied open water, where *Ischnacanthus* chases a shoal of *Mesacanthus*, and a solitary *Euthacanthus* looks for small prey items. After death the fish carcasses and arthropods partially decay before sinking to the deep lake floor to be incorporated in lacustrine laminites. (Modified from Trewin & Davidson 1996.)

representing connection to the sea by rivers overflowing from the lake system, so allowing fish to migrate into the Orcadian Lake.

The Achanarras fish bed has equivalents at other famous fossil fish localities. The Sandwick fish bed in Orkney is the same age and, whilst carrying a virtually identical fauna, shows great changes in relative fish abundance when compared with Achanarras. For example, *Osteolepis* is abundant in Orkney but rare at Achanarras. This may represent proximity of the locality to living areas of the fish.

The same fauna is also found in nodule beds to the south of the Moray Firth. At Tynet Burn (Trewin & Davidson 1999) the laminated fish bed is sandwiched between fluvial sandstones and conglomerates. This was a lake-marginal situation, and the rise in lake level, maybe associated with a wetter or colder climatic period, inundated alluvial outwash plains bordering the Grampian uplands. Again the fish fauna is similar to that at Achanarras Quarry with a few minor specific variations, but the lake margin situation contrasts with the deeper central lake facies at Achanarras where the fish bed is overlain by fine-grained sandstone beds deposited in a deep lake environment by turbidity currents.

Middle ORS - Holburn Head

Apart from the Achanarras fish bed and its equivalents, there are other fish beds scattered through the Flagstone Groups of Caithness and Orkney. One example is the Holborn Head fish bed in the Latheron sub-group of the Upper Caithness Flagstones (Hamilton & Trewin 1994).

At Holborn Head Quarry a 50cm fish bed contains abundant small *Osteolepis panderi*. The fish bed occurs within cyclic lacustrine deposits, which show transitions from deep lake laminites to rippled and mud-cracked sandstones and siltstones of impermanent playa-lakes. The cyclicity was probably climatically controlled, maybe with a Milankovitch periodicity (Hamilton & Trewin 1988, Astin 1990).

Within the fish bed, preservation of fish is variable, with the most fully articulated specimens in the central part of the bed and increasing disarticulation of carcasses towards the margins of the bed. Carcasses are oriented on some bedding planes indicating gentle current activity. Lake expansion lasted for a shorter period of time when compared with the Achanarras event, and water depths were probably less.

The dominance of *O. panderi*, associated with rarer *Dipterus*, and small acanthodians (*Mesacanthus*) is interesting in that there is no large predator present. This factor may have enabled the rapid expansion of the *O. panderi* populations. The similarity in size of individuals involved in mass mortalities suggests that *O. panderi* was a shoal fish, feeding on small prey items, such as freshwater arthropods and worms.

Upper ORS - Dura Den

The Upper ORS consists of the sandy to conglomeratic deposits of rivers; mudstones with caliche soil profiles (cornstones) of alluvial plains, and less frequent aeolian dune sandstones. In the Midland Valley there is a major unconformity beneath the Upper ORS; it rests on folded Lower ORS and older strata, and Middle

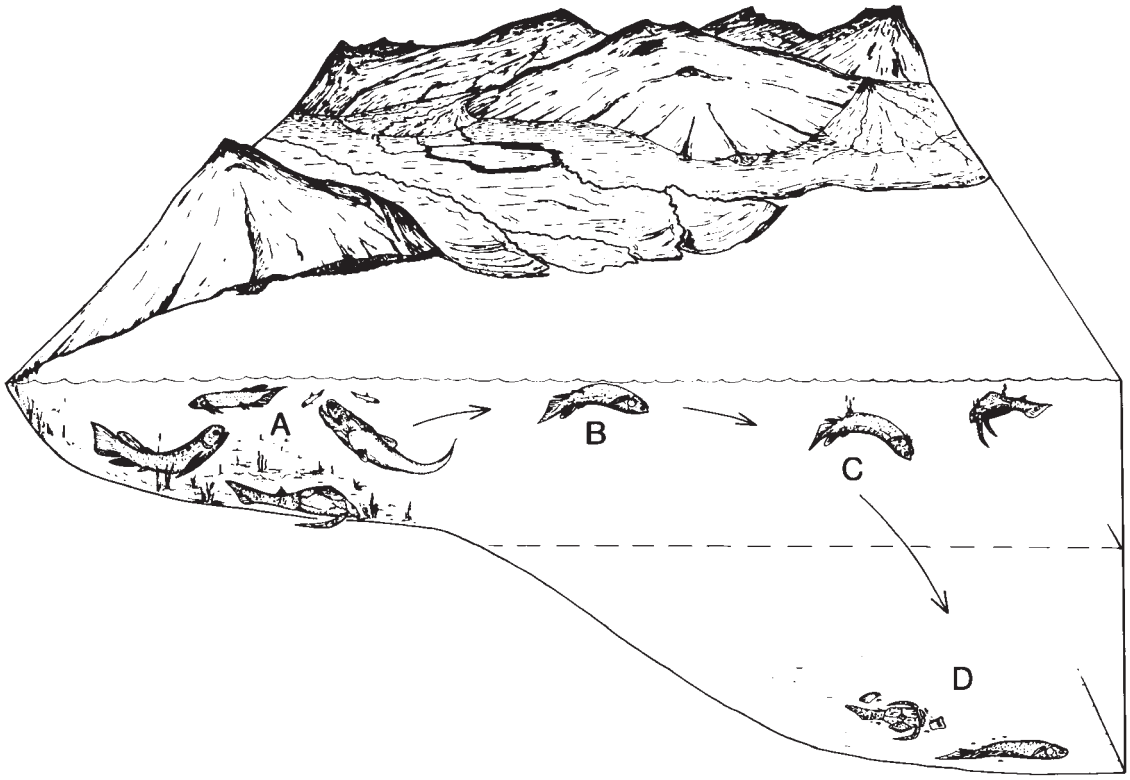

Figure 2. Margins of the Orcadian Basin at the time of deposition of the Achanarras fish bed. Fish (*Pterichthyodes, Glyptolepis, Dipterus* and a *Coccosteus* chasing *Mesacanthus*) inhabited shallow water oxygenated areas (A). Following mass mortalities carcasses drifted (B) to deeper parts of the lake and, following partial decay (C) sank from the oxygenated epilimnion, through the thermocline and were preserved in laminites deposited in the anoxic bottom conditions of the hypolimnion (D). (Modified from Trewin 1986.)

ORS is absent. In this broadly alluvial environment fish inhabited the rivers and shallow lakes and their scales, particularly those of *Holoptychius*, are generally found isolated within fluvial sandstones. In such an environment preservation of complete fish requires special circumstances, and the celebrated occurrence of masses of complete *Holoptychius* together with *Bothriolepis, Phyllolepis, Glyptopomus, Eusthenopteron* and *Phaneropleuron* at Dura Den in Fife (Anderson 1859, Chisholm & Dean 1974) provides a fortuitous glimpse of Upper ORS fish faunas.

Several beds with areas of closely packed fish carcasses are present. The fish occur in sandstone and some are preserved in the round with the carcass filled with sand. Desiccation cracks are present in close proximity to the fish-bearing beds, and it appears that the fish were trapped in pools which dried out, or were invaded and filled by wind-blown sand. The fish-bearing strata are patches possibly up to 50m^2 in area but usually only a few m^2. The benthonic *Bothriolepis* and predatory *Holoptychius* were trapped and dried together with other elements of the fauna. The scene resembles the mortality seen in any dried-up pool, riverbed or coastal lagoon at the present day, but as far as community palaeoecology is concerned the only firm conclusion we can draw is that the fish lived in the same connected body of water.

Conclusions

Scotland is rich in fish-bearing deposits, but few represent an associated community of fish. Preservation of whole fish requires unusual circumstances in which predators and scavengers are denied access to the dying fish and their carcasses. In the lacustrine examples from the Lower and Middle ORS the fish are preserved in deep water with dominantly anoxic conditions, and fish carcasses drifted to the depositional site following mass mortalities in the shallower living areas of the fish. In the Upper ORS, the high energy conditions of the river systems, and well oxygenated waters, mitigated against fish preservation. Rare instances of drying pools, cut off from the main water body, occasionally preserved masses of complete fish. The absence in the Devonian of terrestrial vertebrate scavengers would also contribute to preservation in such situations.

Despite these drawbacks, it is possible to interpret lifestyles of individual fish on the basis of morphological features, and active predators, omnivores and abundant shoal-fish can be identified. Interpretations of their community structure are likely to remain speculative.

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Book reviews

In the Shadow of the Dinosaurs: Early Mesozoic Tetrapods, by Nicholas C. Fraser and Hans-Dieter Sues (eds), 1994, Cambridge University Press 436pp, £24.95 (paperback) ISBN 0521458994 .

During the past twenty years the Cretaceous-Tertiary boundary has attracted much attention reflecting the enormous interest in the end of the dinosaurs. Perhaps because the events of the K/T boundary could possibly happen again, geologists have concentrated on this period of time and neglected the late Triassic and early Jurassic period.

To direct scientific scholarship to the debate on the early Mesozoic, an international work-shop was organised at Front Royal, Virginia, in May 1991 and investigators whose focus is on small tetrapods were asked to contribute to this volume.

The word tetrapod does not appear in any of my O.U. geology course glossaries or geology dictionaries. The introduction to the book makes it clear a small tetrapod is a microvertebrate. Contributions to the book come in geology, biology, palaeontology, anatomy, zoology and earth sciences departments from universities in the U.K., Canada, America, Germany, Mexico and France.

The range of this book is truly global covering China to Nova Scotia and Argentina to Germany. Discoveries and interpretations from fossil beds around the world are presented by each of the thirty five contributors in their own individual way. All of the charts, graphs, stratigraphic columns and geographical maps will easily be understood by any O.U. student who has done a second level earth science course.

The eleven U.K. contributions come from four different universities and the British Geological Survey. The fossil sites and the quarries investigated in the U.K. (approximately 70) have directions as to where they are or map grid reference numbers. Each chapter contains a comprehensive reference list. The total references in this book run into the thousands and there is a taxonomic index.

The book is in three sections.

Part I is concerned with Phylogeny. When I look at some of the taxonomic trees in this section which may have as many as 25 branches, and we are only dealing with tetrapods, then the diversity of life that was in the shadow of dinosaurs must have been as diverse as life is today.

Part II deals with Faunal Assemblages. I enjoyed this section because I found the theory easy to understand. That is, that faunal assemblages begin with "Gondwanan" type assemblages that then evolved in cyclical sequences similar to Milankovitch cycles seen in the Pleistocene and Holocene.

Part III is titled Faunal Change. This section is about extraction and climate change. It is an attempt to improve understanding of the chronology of the Mesozoic period.

I consider "In the Shadow of the Dinosaurs" a valuable reference book for any palaeontologist, zoologist and evolutionary biologist with an interest in tetrapod history in the early Mesozoic.

Fred Counsel BA Hons (Open), continuing Earth Science student

Stone Quarrying by Jo Thomas, 1998, Dovecote Press, 80pp, £4.95 (paperback) ISBN187433661X.

Jo Thomas is a friend of mine, so I knew about this book long before it was published. Jo spent a lot of time and effort researching the history of quarries and the use of stone, both in the library and record offices but she also spent a lot of time literally on the hoof. On several occasions she peered through her hand lens to examine stones in buildings only to feel a tap on her shoulder and hear a kind voice enquire, “Are you feeling all right dear?” These encounters often led to a chat over a cup of tea, the house owner being very willing to tell Jo the family history. As a result there is a lot of previously unpublished information contained in this little book.

Most books on Dorset rocks concentrate on the rich stratigraphy and the fossil content to be found therein. In contrast this book highlights the practical and commercial use of the stone, its aesthetic appearance and weathering potential. It is a pity that the subject has been arranged in stratigraphic (bed by bed) order rather than area by area. If it had been arranged geographically it would have been easier to follow and would have been a book to take along when exploring the area. As part of the *Discover Dorset* series this book complements *Dorset Geology* by Paul Ensom published the previous year. It is well worth £4.595 and useful to have as a reference - but not as a field guide.

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A Caledonian Scottish Assembly

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Abstract

The British Caledonides comprise discrete terranes separated by major structural breaks and recording successive Precambrian to early Palaeozoic development phases of the northern margin of the Iapetus Ocean. Each terrane has distinctive geology that can be characterised by regional geochemical data to provide constraints on terrane relationships across the defining faults. Within the Scottish Highland terranes, the principal geochemical discontinuities coincide with the Moine Thrust Zone, the boundary between the Grampian Group and other Dalradian rocks, and the Highland Boundary Fault. The geochemical evidence provides little support for the Great Glen Fault as a significant terrane boundary. South of the Southern Upland Fault a range of elements indicates division of the Southern Uplands terrane into northern and southern zones. These arise from changes in sedimentary provenance during the early Silurian. The geochemical characteristics of the southern zone continue into the Windermere Supergroup of the English Lake District, emphasising the continuity of Silurian deposition across the Iapetus Suture. Comparison of the surface characteristics of the suture with its deeper geophysical expression suggests that crust originating on the south side of the Iapetus Ocean may extend under much of the Southern Uplands.

The terrane concept was developed during the 1970s to explain large-scale tectonic relationships in the Western Cordillera of North America. A terrane is defined as a discrete allochthonous fragment of oceanic or continental material accreted to a craton (which can itself be regarded as a terrane) at an active margin. The recognition and interpretation of the component terranes of an orogenic belt thus play a valuable part in understanding its development. This presentation assesses terrane relationships in the British sector of the Caledonian Orogen. Only a few key references are cited; comprehensive source bibliographies are given by Plant *et al.* (1999) and Stone *et al.* (1999). A valuable overview is provided by Van Staal *et al.* (1998).

The Caledonian Orogen was created by the destruction of the late Proterozoic to early Palaeozoic Iapetus Ocean and collision between the continents of Laurentia, Baltica and the Avalonian fragment of Gondwana. A necessary precursor was the formation of the ocean during the break-up of the Rodinia Supercontinent. Oceans do not open and close in a wholly orthogonal sense and palaeogeographical reconstructions now tend to regard the proto-Andean margin of Amazonia as the conjugate margin to Laurentia in the late Neoproterozoic (c. 750 Ma). Some go so far as to fit the Scottish promontory of Laurentia into the Arica embayment on the western side of South America. The Caledonian terranes of Scotland record the extension of the Laurentian margin and its subsequent compression through collision with exotic arcs and, finally, Avalonia. The definition of terranes across the British sector of the orogen has tended to concentrate on major structural lineaments, despite well-established geological links across some of them. Six major terranes are generally recognised between the Laurentian continental basement in NW Scotland and the volcanic arc complex of the Avalonian margin in the English Lake District (Figure 1).

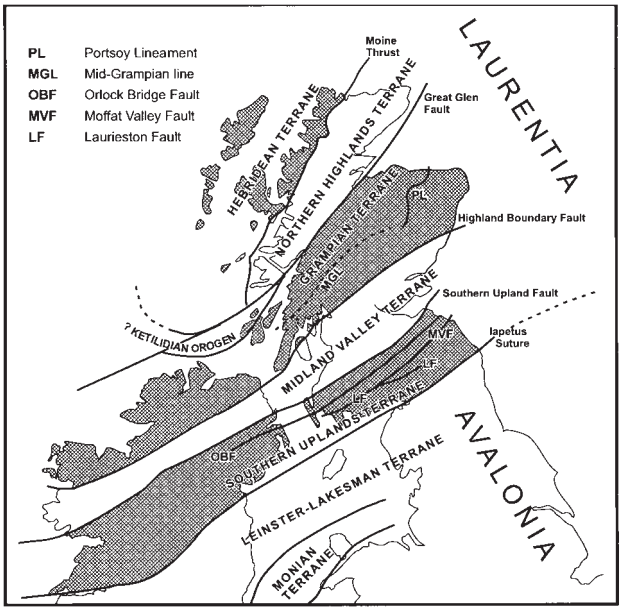


Figure 1. The British Caledonian terrane assemblage. After Stone *et al.* (1999).

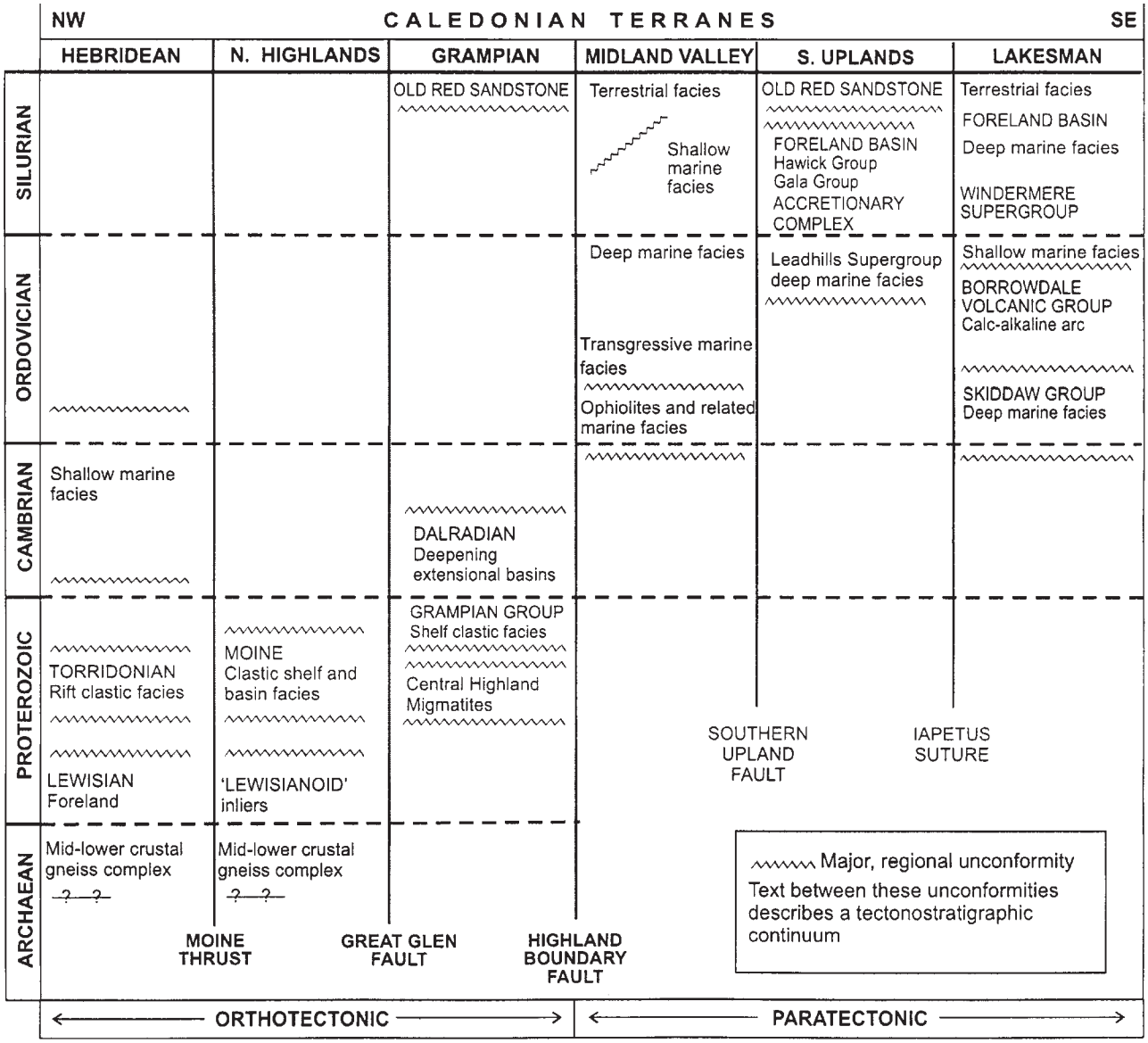
The geochemical characteristics of Caledonian terranes have been illustrated and discussed by Plant *et al.* (1999) and Stone *et al.* (1999) utilising the British Geological Survey's regional geochemical (G-BASE) data. These provide fresh insight into the status of the terrane boundary structures and are particularly suited to assessing possible provenance linkage across the major terrane boundaries. Their most useful application varies between the northern and southern terranes, i.e. the orthotectonic and paratectonic Caledonian zones, respectively to the north and south of the Highland Boundary Fault. Terranes in the north are commonly characterised by complicated lithological relationships and polyphase deformation. This produces a geological diversity that is a formidable barrier to interpretation, but the geochemical data produce a valuable overview, identifying any unifying characteristics and emphasising contrasts, either internally or with neighbouring terranes. The southern terranes tend to have more uniform lithological characteristics and it is their regional homogeneity that makes detailed interpretation difficult. In these cases the geochemical data reveal discontinuities and possible correlations which otherwise remain cryptic.

Geological terrane characteristics

The broad geological characteristics of the Caledonian terranes in Scotland and northern England are summarised in Table 1.

The **Hebridean Terrane** lies to the NW of the Moine Thrust Zone. Archaean and early Proterozoic gneissose basement (the

Table 1. A summary of Caledonian terrane characteristics. After Plant *et al.* (1999).



Lewisian Complex) was intruded by a widespread suite of basic dykes at around 2400 - 2200Ma, intervening between phases of intense deformation and metamorphism. The Lewisian Complex is a fragment of the Precambrian to early Palaeozoic Laurentian continent and has affinities with similar, coeval rocks now seen in eastern Canada and Greenland. It forms the NW margin of the Caledonian Orogen in Britain. The basement rocks are unconformably overlain by relatively undeformed late Proterozoic and Cambro-Ordovician sedimentary assemblages. These are assigned respectively to intra-cratonic rift (Torridonian) and shallow marine shelf environments.

The **Northern Highlands Terrane** is separated from the Lewisian continental basement by the Moine Thrust Zone, the main strand of the Caledonian deformation front in NW Scotland. The terrane largely comprises late Proterozoic clastic shelf or intra-cratonic rift sequences of the Moine Supergroup overlying a "Lewisianoid" basement. Extended, polyphase deformation and metamorphism culminated in Caledonian folding and metamorphism at about 450Ma. The Great Glen Fault forms the SE margin of the terrane but its tectonic status remains controversial. Significant (*c.* 2000km) strike-slip displacement has been proposed and the fault may separate metamorphic terranes of quite different age and origin. Conversely, lithological and geochronological similarities across the fault have been widely cited as limiting any lateral displacement to less than about 200km.

South-eastwards from the Great Glen as far as the Highland Boundary Fault lies the **Grampian Terrane,** composed largely of the late Proterozoic to earliest Palaeozoic Dalradian Supergroup. The geotectonic progression represented is from an intra-cratonic marine environment, with periodic extensional phases, to a fragmented and rifted continental margin with limited spreading-related volcanicity. The sandstone-dominated shelf facies strata of the Grampian Group were deposited in a series of small basins in an intra-cratonic crustal extension zone; they are similar in lithofacies to the Moine psammites. The succeeding Appin Group rocks accumulated in a mainly shallow, marine shelf environment. The younger Argyll Group and Southern Highland Group rocks were mostly laid down in a series of fault-bounded extensional basins; they show marked lateral facies and thickness variations. At the boundary between the Argyll and Southern Highland groups, basic volcanic rocks demonstrate limited generation of oceanic crust at about 600Ma, coincident with the onset

of deep-water turbidite deposition. Polyphase metamorphism and deformation culminated in the Grampian phase of the Caledonian Orogeny between about 490 and 440Ma, probably caused by an arc-continent collision event. The 470Ma layered mafic and ultramafic intrusions emplaced east of the Portsoy Lineament in NE Scotland have been interpreted as products of local extension immediately following the arc collision.

The underlying crustal basement of the Grampian Terrane shows general geophysical similarity to the Lewisian, although differences are apparent across the Portsoy Lineament and the mid-Grampian Line. The Colonsay-West Islay basement is the extremity of a different terrane, possibly linked to the Ketilidian belt of south Greenland. Geophysical discontinuities at the Great Glen Fault appear relatively minor and seismic evidence establishes a major crustal break, which probably coincides with the southern limit of the Laurentian craton, further south, close to the Highland Boundary Fault.

The Highland Boundary Fault forms a major tectonic break to the south of which the Caledonian rocks of the **Midland Valley Terrane** are largely obscured by Upper Palaeozoic strata. Dismembered Caledonian ophiolite assemblages are preserved in small, isolated outcrops at the northern and southern margins of the terrane: the Highland Border Complex in the north, and the Ballantrae Complex in the south adjacent to the Southern Upland Fault. The oceanic arc and marginal basin assemblage of the Ballantrae Complex was obducted onto the Laurentian margin, at about 480Ma, as part of a widespread arc-continent collision event which may have caused the Grampian orogenic phase further north.

To the south of the Southern Upland Fault lies the **Southern Uplands Terrane** which formed as an accretionary thrust complex at the Laurentian continental margin during late Ordovician to mid-Silurian subduction of the Iapetus Ocean. It has been widely interpreted as a forearc, supra-subduction zone prism, although the terrane may alternatively have developed from an Ordovician back-arc setting into a mid-Silurian foreland basin which migrated onto the Avalonian continent following closure of the Iapetus Ocean. Either model accommodates the structural configuration of southward propagating imbricate thrusts separating tracts of steeply inclined, turbidite-facies greywacke beds. Internally the tracts have an overall sense of younging towards the north whereas the minimum age of each tract decreases southwards. This diachronous tectonostratigraphic pattern means that compositional variation in sequentially younger greywackes incorporated at the thrust front will reflect provenance changes induced by major tectonic adjustments during closure of the Iapetus Ocean.

There is geophysical evidence for major crustal discontinuities beneath the Southern Uplands, to the north of the generally accepted line of the Iapetus Suture along the Solway Firth (Kimbell & Stone 1995). A significant break coincides with a wide shear zone at the surface (the Moniaive Shear Zone) which separates two compositionally different assemblages of intrusive granitoids and basic dykes. Since the crustal basement between the shear zone and the Iapetus Suture has Avalonian geophysical characteristics it could have been a microcontinental or arc remnant swept up during closure of the Iapetus Ocean and trapped on the "wrong" side of the Suture.

On the southern side of the Iapetus Ocean the English Lake District forms part of the **Leinster-Lakesman Terrane**. Therein, the Tremadoc to Llanvirn Skiddaw Group was deposited in an ensialic extensional basin at the Avalonian margin as that microcontinental block rifted from Gondwana. Subduction at the northern Avalonian margin caused inversion of the Skiddaw Group basin prior to the mainly Caradoc eruption of the Borrowdale Volcanic Group, and intrusion of a sub-volcanic batholith. Cessation of volcanicity and slow thermal subsidence during the early Silurian was followed by abruptly accelerating subsidence from the late Wenlock as the Iapetus Ocean closed and the Laurentian margin over-thrust the Avalonian continent. The foreland basin originating in the southern sector of the Southern Uplands migrated southwards across the Iapetus Suture and into the Avalonian hinterland. The Laurentian - Avalonian continental collision was followed some 20 million years later by Acadian tectonism during the early Devonian. The Acadian event was perhaps initiated by the arrival of another Gondwanan continental fragment at the southern margin of Avalonia.

Geochemical terrane characteristics

The British Geological Survey's regional G-BASE data are derived from analysis of stream sediments collected at a density of approximately one sample per 1.5km^2. Although northern Britain has been extensively glaciated there is systematic agreement between the values of many chemical elements in rocks and the geographically coincident sediments. This means that the regional geochemical data can be used as a surrogate for whole rock data to illustrate chemical variation between adjacent terranes or within any one terrane. Multi-element comparisons are most effective, grouped as follows:

- elements thought to be associated primarily with feldspar and/or mica (K-Ba-Rb-Ca-Sr).
- elements which generally have high levels in ultrabasic or basic rocks (Cr-Ni-Mg-Co-Cu-V-Ti)
- elements commonly concentrated in detrital heavy minerals (e.g. Zr in zircon, Ti in rutile, ilmenite and sphene, Y in garnet and monazite, Cr in spinel).

Plant *et al.* (1999) and Stone *et al.* (1999) identified several crustal sectors which have distinct geochemical characteristics and suggest the following principal compositional boundaries in the Caledonides: the Moine Thrust Zone; the Grampian Group-Appin Group boundary; the Highland Boundary Fault; the Southern Upland Fault. On the basis of the geochemical data the Great Glen Fault does not appear to represent a major geological discontinuity. In the case of the Iapetus Suture, between the Laurentian and Avalonian plates, a range of element associations, such as Cr-Ni-Mg and Rb-Sr-K-Ba, identify a complex zone extending across strike from the Southern Upland Fault to the southern Lake District.

The geochemical signatures of the terranes also allow assessment of their potential as possible sources for later deposits. The presently exposed Lewisian Complex (Hebridean Terrane) seems unlikely to have been the main source area for either the Torridonian or the Moine psammites (Northern Highlands Terrane). Further south, the Dalradian (Grampian Terrane) does not appear to have contributed much sediment to the Southern Uplands with the possible exception of the oldest strata there. Hence, the geochemical patterns do not require pre-Silurian terrane assemblage at the Laurentian margin. The division of the Southern Uplands into two sectors is apparent from a range of

element associations. The dividing line is not consistent with any particular structure, but the combined Moffat Valley and Laurieston faults seem most likely to mark the boundary between active or extensional margin (northern) and foreland basin (southern) components. The latter can be traced into the Windermere Supergroup of the Lake District (Lakesman Terrane), consistent with the southward progression of the Southern Uplands thrust belt, across the Iapetus suture zone and onto the Avalonian continental margin following collision with Laurentia.

The Iapetus Suture Zone

The geochemical patterns across the Southern Uplands Terrane are particularly informative since they reveal cryptic compositional divisions of the relatively uniform greywacke bedrock. The most striking distribution pattern for many elements is striping on a NE-SW trend parallel to the regional strike of the steeply inclined beds, reflecting variations in greywacke composition.

Regional levels of the ultrabasic and basic components, Cr, Ni, Co, Mg and V, are very high over the Southern Uplands Terrane. Immediately to the north, the Ballantrae ophiolite complex comprises ultrabasic and basic rocks and might form an appropriate provenance. However, in view of the considerable strike extent of ophiolitic material along the Laurentian margin, the juxtaposition with the Ballantrae Complex, across the Southern Upland Fault, may be fortuitous and should not be regarded as constraining lateral movement on that structure. By the late Ordovician the ophiolitic rocks, at least in the Ballantrae Complex, were buried beneath a thick turbidite sequence and were no longer available for erosion. Significantly, the maximum Cr values in the central part of the Southern Uplands are spatially associated with part of the early Silurian (Gala Group) outcrop. These strata lie within the *acuminatus* to *gregarius* graptolite biozones of the early Llandovery, indicating that the influx of ophiolitic detritus reached a maximum at that time. Palaeocurrent data prove that the Gala Group was consistently derived from the NE in terms of present-day geography and, in that direction, the Scandian Orogen was initiated in Llandovery times. Erosion there of Scandian ophiolites would provide a possible source of the Cr-rich detritus subsequently carried southwestwards and incorporated into the Southern Uplands greywackes.

Across the Southern Uplands the feldspar-related elements, Rb, K, Sr and Ba, define two or three distinct greywacke populations. The Rb and K distributions define a zone of relatively low values corresponding to the Ordovician sequence north of the Orlock Bridge Fault and a relatively high-value zone corresponding to the Silurian sequence south of that structure. The Sr distribution shows a complementary reverse pattern but with the abrupt change further south, across the Moffat Valley Fault: relatively high values occur to the north and lower values to the south. The Ba distribution is apparently controlled by both of these major structures, with a marked zone of high Ba bounded to the north by the Orlock Bridge Fault and to the south by the Moffat Valley Fault. The combination of low Rb, K and Ba with high Sr over the Ordovician greywackes suggests that they contain a high proportion of detrital plagioclase feldspar derived from rocks of a dioritic or granodioritic composition. The converse relationship south of the Moffat Valley indicates that detrital potash feldspar is relatively more abundant and implies that the greywackes there had a provenance largely within more evolved continental crust. The discrepant correlations across the older part of the Silurian sequence, between the Orlock Bridge Fault and the Moffat Valley - Laurieston faults, suggest the interaction of different provenance areas rather than the geochemical evolution of a single source. It may be significant that the discrepant correlations occur across the same sequence that received the maximum ophiolitic input; both effects may reflect the same large-scale tectonic adjustments within the orogen.

Variations in the abundance of other elements associated with a detrital heavy mineral fraction, such as Ti, also have a close spatial relationship with lithostratigraphical boundaries. For example, the highest Ti levels occur in the northern sector where they extend across Ordovician greywackes of quartzo-feldspathic composition. The abrupt southern margin of this high-Ti zone coincides with a lithostratigraphical boundary and, to the south, lower Ti levels are found over greywackes rich in andesitic detritus. A second downward step in Ti abundance occurs further south within that part of the Silurian sequence where transitions in provenance are also apparent in the feldspar-related and basic elements.

On the south side of the Iapetus Suture the regional geochemical signature of the Windermere Supergroup is very similar to that seen over the southern sector of the Southern Uplands Terrane, south of the Moffat Valley Fault. The feldspar-related elements suggest a provenance in moderately evolved continental crust with relatively high levels of Rb and K but relatively low Sr, continuing the pattern developed across the Southern Uplands. The low levels of Ti, Zr and Y seen in the southern sector of the Southern Uplands are also apparent over the Windermere Supergroup, as is the characteristic elevation of the basic and ultrabasic elements. Levels of Cr and Ni are somewhat lower than those seen over the central Southern Uplands but remain generally high. An external provenance is necessary since the Borrowdale Volcanic Group, which is unconformably subjacent to the Windermere Supergroup, is depleted in Ni and Cr and so could not act as their source. Thus, a similar provenance to that supplying the Southern Uplands is required, with moderately evolved continental crust sourcing the feldspars and a probable ophiolitic provenance for the ultrabasic components. Palaeocurrrent analysis confirms that much of the Windermere Supergroup foreland basin sediment was derived from the NE, in agreement with a regional model whereby the Scandian Orogen shed sediment south-westwards into the closing Iapetus Ocean for much of the Silurian, from the middle Llandovery onwards.

Conclusions

Regional geochemical data for the orthotectonic British Caledonides identify a major compositional break coincident with the Moine Thrust, confirming its status as a terrane boundary. Conversely, the data provide little support for the Great Glen Fault as a major structural discontinuity. A significant compositional change occurs coincident with the boundary between the Grampian and Appin groups within the Dalradian sequence of the Grampian Terrane. Strong compositional contrasts are also apparent across the Highland Boundary and Southern Upland faults.

In broad terms the regional geochemical data militate against the derivation of Southern Uplands Terrane strata by erosion of older terranes currently seen to the north. The feldspar-related elements show a systematic variation through the Southern Uplands

stratigraphy that would be difficult to relate to a sequence of sources within the exposed orthotectonic Caledonides. The high Cr levels are a notable feature, far exceeding the levels generally seen to the north over the Grampian and Northern Highland terranes. Conversely the Ti levels, generally high over Dalradian strata younger than the Grampian Group, decline abruptly southwards across the Southern Uplands, seemingly incompatible with a unique Dalradian provenance.

The overall implication of the G-BASE data interpretation is that the Southern Uplands Terrane need have had no pre-Silurian connection with the orthotectonic Caledonian terranes of Scotland. Conversely, it supports the idea that by the mid-Silurian the Iapetus Ocean had effectively closed with a single depositional system spanning the suture. This formed as the Laurentian margin over-thrust Avalonia, preceded by a foreland basin migrating towards the Avalonian hinterland. The Wenlock to Ludlow upper part of the Windermere Supergroup, which forms the southern sector of the English Lake District inlier, was deposited in this foreland basin. It is the tectonostratigraphic successor to the Southern Uplands thrust belt, with which it shared a Scandian provenance through the Silurian.

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Book review

Geology of the Airdrie District by I H Forsyth, I H S Hall & A A McMillan, 1996, BGS, 94pp, £37.50 (paperback) ISBN 011884508X.

A rather splendid colour photograph of the Clyde Plateau Volcanic Formation is a fine start for the Geology of the Airdrie District, memoir for the BGS 1:50000 Sheet 31W. The contributors list geophysics, palaeontology and hydrogeology as their interests. The geology begins with the Devonian and ends with the Quaternary but the bulk of it is in the Carboniferous with four chapters devoted to the various divisions of that Group of rocks while a fifth deals with the late/post intrusive igneous rocks. Structure, Economics and Geophysical investigations are also covered so it is a pretty comprehensive volume. It is also the first general account since 1879 which includes the geology of Eastern Glasgow. The area covered stretches from the Kilsyth Hills to the Cathkin Braes and to Cumbernauld and Airdrie.

The printing is clear and in double columns. The figures and tables are neatly done and I could read even the complicated ones. There are plenty of photographed locations and fossils, in black and white; quite sufficient to illustrate the subjects. There ís a long list of useful references, four appendices on maps, boreholes, and GS photographs available for the area. There is also a fossil as well as a general index. It is, of course, full to the brim with useful information on the area. My favourite photograph is Plate 9, the laminated silts and sands of the Paisley Formation showing folding and small scale thrust faulting at Foxley Pit in Lanark, which gives a small scale but very clear picture of such events.

This is a book I would be only too happy to put on my shelf if only I could afford it. At £37.50, and with so many others becoming available at similar prices, I must regrettably forgo it.

Doreen Smith BSc and continuing Earth Science student

Ecology: Principles and Applications 2nd Edition by J L Chapman & M J Reiss, 1999, Cambridge University Press, 330pp, £20.95 (paperback) ISBN0521588022.

Here we have a "comprehensive textbook for A-level students and first year under-graduates taking courses in biology, geography and Earth sciences, who require an introduction to ecology." This revised edition incorporates more information on conservation.

The authors hope that the book is 'readable rather than daunting', an objective which they have achieved. It is well presented, clearly laid out and illustrations are generally good. All the elements necessary for an ecology textbook are there, starting with an introduction to the subject and then devoting well-sorted chapters to the individual, population dynamics, ecological genetics, habitats and niches, biomes, etc., etc. Thankfully we are not overwhelmed with mathematics before our interest in the subject is aroused. I liked the principle of presentation of a topic followed, where appropriate, by a case history. For example Chapter 3 on autoecology gives a definition - then we have studies first of bracken then of starlings. Each chapter ends with a summary, invaluable for the student needing to absorb the main points of the subject.

There are some irritations. Within a few paragraphs we meet Gondwanaland 5 times and Gondwana 4, as though someone could not make up their mind. And we are told as a fact rather than a theory that the extinctions at the end of the Cretaceous were caused by a giant meteor (sic) hitting the Yucatan Peninsular. Now then chaps, look up meteor and meteorite. But was it not an asteroid, anyway? Certainly Earth science students should be aware of an alternative theory that intense volcanic activity took place at this time, and that the huge basalt deposits of the Deccan traps of India have been dated to the KT boundary. As the book goes on to mention the even greater extinctions at the end of the Permian, it would have been instructive to note that Renne & Basu (Science. v253, pl76, 1991) have dated Siberian traps to this time. The chapters on conservation, and encouragement to be involved are welcome. After all, what is knowledge of ecology for, if not to be put to practical use? However,coming from a practical background in nature conservation myself I found some of the writing woolly. Connections between religion and looking after the Earth are discussed. This is followed by "many who have no religious convictions "still" ....try to save rare species and pristine habitats". Wow! Really?

Sites of Special Scientific Interest (SSSIs) are mentioned but not Sites of Biological Importance (SBIS) which are more numerous and where the bulk of conservation in Britain takes place. And no mention of RIGS!

Summing up: a good readable textbook on ecology,which will be very useful to its targeted readership, but would have been even better had a geologist/conservationist taken a pencil to it first.

Tony Browne BA Hons(Open)

Book reviews

Deformation-enhanced fluid transport in the Earth's crust and mantle by M B Holness (ed), 1997, Chapman & Hall, 333pp, £69.00 (hardback) ISBN 0412752905.

Published in the Mineralogical Society's Series of reviews, this book is a report of papers presented at a meeting of workers from different branches of geology who share an interest in the mechanisms and effects of fluid flow in rocks. A large part of the Earth's volume contains a fluid phase in the form of melt or as volatiles such as gas and water. This faction is rarely static and movement of fluids affords also the transport of heat and matter within the Earth resulting in, for instance, formation of oceanic crust, granites and hydrothermal minerals.

The book is edited by Marian Holness who also wrote the first chapter about permeability-porosity relationships in non-deforming rocks, ie fluid flow paths in rocks under hydrostatic stress. This forms a simple basis against which fluid movement under deformation conditions is compared in the rest of the book.

Chapters 2 & 3 concern experimental studies which conclude that low stress deformation promotes grain boundary migration and thus melt movement.

Building on this, Chapters 4 to 7 put forward various mechanisms for the ascent and emplacement of granitic melt modelled on both experimental work and field evidence. Current research points to transport of granitic melt via dykes and deformation zones rather than diapirs rising through the crust.

Chapter 8 turns to fluid flow during prograde regional metamorphism where pore geometry is controlled by the kinetics of reaction and crystal growth. This chapter includes field evidence from a Scottish Highlands case study where fluid movement was found to be channelled along the banding formed by metamorphic mineral alignment.

Chapter 9 reports on investigations into the geochemistry of fluid-rock interactions to trace flow paths in ductile shear zones. And finally, Chapters 10 & 11 concern shallow crustal vein segregation and fluid movement in fractured crust including flow models of interest to those employed in minerals extraction, rock engineering and waste industries.

Because the book was produced for a very narrow audience it is rather pricey at £69.00 for 300 pages but for those studying rock deformation it forms an invaluable account of research in progress and includes many pages of useful references. However, the depth of explanation and many diagrams in each paper should make it readable and interesting also for non-specialists - borrowed from the library, of course! Those studying OU geology courses will no doubt find it interesting to read about the work behind current theories favouring dykes as opposed to diapirs for the ascent of granitic melt through the crust.

Chris Arkwright, BA Hons (Open), MSc (Man),
OU tutor and continuing PhD student of rock deformation in dehydrating serpentinites.

Contaminated Land: the practice and economics of redevelopment by Paul Syms, 1997, Blackwell Science Ltd, 308pp, £41.50 (hardback) ISBN 063204134X.

I was attracted to this book because of local problems with soil contamination following lead mining operations, hoping for an insight into the techniques of site investigation and methods of treatment of contaminated soil. The book certainly provides an introduction to these topics and useful references for further study but also a whole lot more for those interested in the development of former industrial sites in place of greenfield sites.

The book is divided into four sections. The first discusses what soil contamination is and the ways in which contaminants may travel, as well as relevant legislation. The second section deals with the technical issues, such as site investigation and methods of treating contaminated soil together with the risk based approach to remediation of contaminated land. It is this section which is of most interest to Earth scientists and describes the main phases of site investigation, sampling and analysis as well as the soil treatment options available. Possible approaches to the assessment of environmental and economic risk are discussed using useful case studies. In section three, attention is turned to the redevelopment and valuation issues, using a number of case studies and describing the results of recent research. Section four addresses the issues of satisfying regulatory authorities and the potential users of contaminated sites that are suitable for use.

The author has provided a very readable product of a technical subject which is enhanced by the use of photographs, checklists, case studies and references. The emphasis of the book is upon the redevelopment of land following treatment and the economic and valuation issues and is aimed at developers, investors, property valuers, regulatory authorities and the occupiers of completed developments. Although the book is intended as a professional text, it will be of interest to those involved in education and research concerning contaminated land and readers with a general interest in environmental issues. The book is structured in such a way as to be read either from cover to cover or to be dipped into. Students studying S268 would find it interesting background reading particularly Sections I and 2 whilst environmentalists and anyone involved in planning issues would benefit from reading the whole book. At a purchase price of £41.50, students would be advised to seek out a library copy, although for those directly involved in this field of work it is a must for the bookshelf.

Dr Alan Seago B Sc (Hons),
Ph D OU Tutor S268, S267, S338

The Biosphere by Vladimir L Vernadsky, translated by David B Langmuir, revised and annotated by Mark A S McMenamin, 1997, Springer-Verlag, 192pp, £19.00 (hardback) ISBN 038798268X.

The kind of ideas behind this book, first published in Russia in 1926, are those familiar to OU students through S269, Earth & Life, and to a wider public through James Lovelock's "Gaia hypothesis". It is the discipline of biogeochemistry, the notion that ever since life appeared on earth it has been a major factor in the chemistry and indeed the geology of Earth, so that one can speak of a biogeochemical evolving system. As the Foreword puts it, "Observation and measurement today of the flow of carbon, sulphur, and nitrogen through the hydrosphere, atmosphere and biota are practices based on the style of thought invented by Vernadsky."

But very little of Vernadsky's work was known directly in the West until recently; even James Lovelock remained unaware of it until well after he framed his "Gaia hypothesis". Teilhard de Chardin had heard Vernadsky lecture in Paris in the early twenties and, like him, took up and developed the term biosphere which the Austrian geologist Eduard Suess had pioneered (in a limited sense) in 1875. But Teilhard, long in China, probably did not read the 1929 French translation, La Biosphère, and his view of life remained anthropocentric, while Vernadsky's was biocentric. The first English translation was made in the 70's but known only in typescript until the present edition, while a bowdlerised translation of the French edition was produced in 1986 to support the Biosphere 2 project - bowdlerised to remove anything that might be considered "wrong" in the light of scientific discoveries of the previous 60 years!

It is certainly good for anyone interested in the history of scientific ideas - those for instance who have done, or might do, the OU's excellent AS283, The Rise of Scientific Europe, 1500 - 1800 to have available this pioneering work and excellent to have it in such a beautiful format. Like so many American books, it is a pleasure to look at and to handle. The foreword and introduction are fascinating, and the annotations are often extremely illuminating. Mistakes Vernadsky made are gently pointed out (not excised!) - such as his assertion: "the realm of photosynthesizers in [the Archaean Era] was the source of free oxygen, the mass of which was of the same order as it is now". On which the comment is: "This incorrect line of argument helps explain why Vernadsky missed the connec-

tion between oxygenation of the atmosphere and the Precambrian banded iron formations" - a subject horribly familiar to S269 students!

Philip Clark, continuing Earth Sciences student.

Gaia's Body: Toward a Physiology of the Earth by Tyler Volk, 1997, Springer Verlag, 269pp, £19.00 (hardback) ISBN0387982701.

Despite my wife's reservations after viewing the dust cover, this is not some racy novel! It is one man's view of Gaia, that interacting system of ocean, atmosphere, soil and life that has been brought to our attention by such scientists as Jim Lovelock and Lynn Margules. Volk's objective is to present a physiology of Gaia: to understand its key components and to understand the flows of energy and the cycles of materials, together with the feedback loops that control them.

The book comprises eight chapters. The first chapter, entitled 'Breathing of the Biosphere', focuses on the famous sawtooth graph of atmospheric CO^2 concentration measured at Mauna Loa, Hawaii, and seeks to uncover the underlying cause and effect relationships that control this annual oscillation. This chapter, and the succeeding chapter, set the tone of the whole book : abandon it here if you can't handle it! The next chapter, 'Outer Light, Inner Fire' examines the interaction of Gaia with the solar energy flux which powers the atmospheric and oceanic circulations and with the Earth's internal heat which powers many of the material transfer cycles via plate tectonic processes.

The following two chapters focus on the component parts of Gaia at different levels, from global to microscopic, but taking a holistic view rather than the usual reductionist approach - for example, showing how the disparate kingdoms of plants, algae and cyanobacteria should be viewed as a single 'biochemical guild' of photosynthesisers. Chapter 6, entitled 'Embodied energy' explores how biochemical energy is used to drive a multitude of chemical transformations within Gaia. Chapter 7 picks up again the theme of cycles of elements through Gaia, while the final chapter focuses on the emergence and development of the various 'biochemical guilds' from the Archaean to the present day.

This book comprises a good balance of serious science and entertaining narrative: it is not a textbook of geophysiology, but nor is it light bedtime reading. It should be of interest to all Earth Scientists; those studying the Oceanography or Earth & Life courses will find much valuable background material to supplement their OU course units.

Duncan Woodcock BSc Hons (Open)

Whisky on the Rocks, origins of the "water of life", by Stephen and Julie Cribb, illustrated by Richard Bell, 1998, BGS, 73pp, £6.50 (paperback) ISBN 0852722907.

This delightfully informative and charmingly illustrated book opens with an Everyman's vision of the pouring wet Highlands and an unperturbed Hielandman with his wee dram. Below him is a sunny bay, with a Puffer steaming in towards a distillery. Surrounding the watercolour is the legend "Nine hundred billion litres of rain fall on Scotland each year, from this, nine hundred million litres of whisky are produced. This is the story of that water and that whisky...." This sets the tone of the book.

The process of production of this possibly "greenest" of drinks is described. The author proceeds to a succinct, illustrated overview of the derivative waters and a clear description and interpretation of the geology of Scotland. Areas of whisky production are then related, chapter by chapter, to the great geological blocks and the 91 different rocks through and over which the waters flow.

The text is enhanced by illustrative watercolours throughout, brightly-coloured, explanatory geological diagrams and satellite images. A glossary at the end makes this a near-perfect introduction to the geology of Scotland for the neophyte, as well as an excellent present for the discerning whisky drinker. Altogether a welcome addition to the "Earthwise" series.

Rosalind M Wilson

BGS Earthwise Publications: London's Westminster, by E Robinson & M Litherland, 1997, ISBN 085272294X; St Paul's by E Robinson & M Litherland, 1997, ISBN 085272958; Lake District by P Stone & A Denniss, 1997, ISBN 0852722966; Fossil Focus on Foraminifera by I Wilkinson, 1997, ISBN 0852722982; all A3 folded, £1.95 each.

I have four of these well priced, colourful, eyecatching and informative leaflets in front of me. They are A3 folded in three which makes them a little large to fit in a pocket but the board is stiff enough to bear handling and there is sufficient room on each for maps, diagrams and plenty of information.

Two of them are Holiday Geology Guides to London's Westminster and St Paul's area. Each has a bird's eye view of buildings. Each has a detailed description of the materials used in the construction of those buildings round the edge of the map. The back page has a geological time scale with relevant rocks in place, plus illustrations of the uses some of them have been put to in the area. The other back page tells the story of the ages the sites have passed through from the Chalk underlying both to the present day.

The Holiday Geology Map is of the Lake District with a satellite view of the area plus a column explaining the relevance of geology to the present day landscape and a cross section as well. The two back pages then give a photographic explanation of the same relevance. Plenty of pictures, easily read script, the sort of useful material to have in hand when standing at one of the sites so described.

The fourth of the leaflets is a Fossil Focus on Foraminifera. The inside has detailed drawings and explanations of what is a foraminifera plus a variety of their forms, explanations of how they reproduce, live, what affects their development, their environment. The back page has a time column with a geological history of foraminifera development, very colourful and with more forms of tests while the final page has a short human history of their recognition and uses of the limestone in which they are to be found.

I think these are all excellent productions which are likely to attract the general public enough not only to buy them but also to use them to foster interest in geology and its relevance to all of us. May there be many more.

Doreen Smith BSc and continuing Earth Science student

Directory of Mines and Quarries by D G Cameron et al, 1998, BGS, 197pp, £55.00 (paperback) ISBN 085272313X.

The directory was first published by the British Geological Survey in 1984. This is the 5th Edition. It is derived from a database of 2400 entries, each of which describes an individual onshore mineral working in terms of its name, ownership, basic geology, commodity produced, and in some cases the use of that commodity. It also lists mineral workings by Mineral Planning Authority area and an alphabetical list of company addresses.

This latest edition has taken account of recent unitary authority boundary changes; however, the reader may be confused to see names such as Hereford and Worcester still entered as one county, whilst others such as Telford and Wrekin are left out.

The introductory pages contain a useful guide to the information within the directory, also some very informative tables on mineral production.

The directory is divided into 3 parts:
Part l: Mineral workings grouped by mineral commodity produced and by Economic Planning Regions in which located. The workings are also arranged alphabetically by M.P.A., with Grid references.

Part 2: Contains a list of Mineral operators. Mineral Planning Authorities are arranged alphabetically. Companies are listed within those counties.

Part 3: This has an alphabetical list of operators including address, telephone and fax numbers and respective operations.

The directory will be a useful reference for anyone doing research into mineral production in Britain. It will also be of interest to Earth Sciences students (particularly S268) who wish to obtain more detailed information on mineral production. Finally, I would use it as Branch/Event Organiser to identify potential places of interest to visit. A word of warning though. At £55 per copy, it is expensive particularly if it will only be used very occasionally.

Throughout my review I kept thinking "It would be a lot easier to access on floppy". I could find no indication within the directory to suggest that an alternative version was available.

Ron Whitfield, continuing Earth Science student

Analysis of Sediments and Sedimentary Rocks by DH Krinsley, K Pye, S Boggs Jr and N K Tovey, 1998, Cambridge University Press, 193pp, £50.00 (hardback) ISBN 0521453461.

During my work on sands, I have been fortunate enough to have had access to a scanning electron microscope (SEM). Using Backscatter (BSE) is a common technique but, until now, I had not come across a book that dealt with sedimentary rocks in the detail that this book does.

The first section of the book gives the reader an insight into how an electron microscope works and how to prepare the samples. These samples can be the standard thin section or a polished rock chip. Staining and other normal techniques can be used to enhance the sample. The major difference is that, for operational reasons, the sample has to be coated with a thin layer of carbon prior to examination.

The principle of an electron microscope is simple; a beam of electrons is fired at the sample and as they hit the sample some electrons are reflected or scattered out of the material at high angles. These electrons are collected and used to produce a grey level photograph that contains both compositional (atomic number) and topographic information.

Because an image in BSE mode has a greater resolution than can be produced with an ordinary light microscope, BSE is used in sedimentology to provide textural data that are somewhat similar to those obtained from a light petrographic microscope but at much greater resolution. Thin sections can be observed at magnifications from 25 to 20000 times. The mineralogy and porosity of very fine grains can be obtained and information on diagenetic alteration including cementation and replacement can be acquired. Thus the BSE SEM can give new insights into sedimentary rocks.

The book moves on to look at grains, weathering and diagenetic phenomena. It gives many examples of how BSE has resulted in a new understanding of microfine structures and how alteration of minerals has taken place. This chapter is well illustrated and case histories are used to explain the way in which the information relates to the real world. One such study was that of the catastrophic failure of the shale embankment dam at Carsington, Derbyshire in 1984. The study showed that displacive growth of secondary gypsum crystals played an important role in disrupting the shale fabric and increased the porosity by up to 10% with the significant implication for its geotechnical use at the site. Information that could not have been obtained without the use of BSE.

The next few chapters consider the use of BSE in a more specific way in the fields of cements, textures and porosity. These are followed by chapters on individual rock / mineral types such as shale, authigenic minerals and glauconite. These chapters provide a wealth of information for anyone studying these rocks / minerals.

The final chapters look at the analysis of the obtained images and bring in the application of energy dispersive X-ray analysis (EDX). EDX is a technique whereby X-rays emitted from the sample are collected and, by using a computer to analyse them, information can be obtained on the atomic elemental makeup of the sample.

Overall the book is well written and explains the principles as well as the results. It is a book that is as readable and useful for the undergraduate as it is for the long time researcher. There are over 150 photographs to accompany the text and many line diagrams to illustrate principles. At £50, the book is not cheap but in the specialist market it is aimed at does show value for money. I certainly would not object to it being on my Christmas list.

Phil Ingham

Lyell: the Past is the Key to the Present by D J Blundell and A C Scott (eds) 1998, Geological Society Special Publication No 143, 376pp, £79.00 (hardback) ISBN 1862390185.

How could I resist the chance of reading this after being involved in organising our Symposium at Swansea, which had practically the same title?

Charles Lyell published the Principles of Geology in 1831 and the next year gave a series of lectures based on his book which attracted audiences of 100 or more, several times rising to around 300. Interestingly, when he repeated the lectures the following year women were only allowed to attend the first one, on the grounds that they were a distraction to the students. The audiences dwindled to 15. It isn't clear whether this was because the female part of the audience was a greater attraction than Lyell's lectures, or because more women than men were interested in his subject!

Lyell: the Past is the Key to the Present is a collection of 23 papers and is divided into 3 parts, each with an introduction by the editors. As with all Geological Society Special Publications, printing and binding is of a high quality and illustrations are clear and well presented, including many reproductions of Lyell's own work. The price is £79.

In Part 1, The life and influence of Lyell, authors consider Lyell's Principles of Geology and his connections with the Geological Society (of which he was a member for 56 years, from the age of 22). A paper is devoted to biography, followed by another considering the diffusion of his works through Europe, where his ideas were hotly debated. Lyell also travelled to North America, lecturing there between 1841 and 1853, and acquiring fresh knowledge from the professional geologists he visited there. In 1863 Lyell published The Geological Evidences of the Antiquity of Man which contributed to the founding of two scientific disciplines: Prehistoric Archaeology and Palaeoanthropology.

Part 2, Lyell and the development of geological science, begins with a paper examining Lyell's contribution to the interpretation of sedimentary rocks through "present causes" and makes a case for Lyell being the true originator of sedimentology and basin analysis. This is perhaps the best known aspect of Lyell's work and the basis of the often quoted aphorism that "The Present is the Key to the Past", from which this Book derives its title.

Other papers in this section look at Lyell's chronostratigraphy of the Cenozoic Era, at his views on evolution and extinction, at the age of the Earth and invention of geological time and at the Quaternary glaciation and at climate change. The relevance of catastrophism and uniformitarianism to modern geology are discussed, and the section concludes with a paper by John Mather, the Lyell Professor at Royal Holloway College, which looks at the development of British hydrogeology in the nineteenth century. Professor Mather considers the vast demands placed on water resources during the Industrial Revolution: by the middle of the nineteenth century it was realised that groundwater was a finite resource. An explosion of activity in the 1870s resulted in the birth of the science of hydrogeology and the first hydrogeological map and, by 1899, the first water supply memoir.

In the final part of the book, The legacy of Lyell, a set of papers considers developments in geological sciences since Lyell's day. Topics range from the evolution of Iapetus, through our knowledge of coal bearing strata, and the Carboniferous evolution of Nova Scotia, to a paper by Professor Chris Wilson of the Open University on sequence stratigraphy (a revolution without a cause?). There are discussions of extrusions of

salt in Iran, monitoring Mount Etna, and Earthquakes and Earth structure, and the book ends with Sir John Knill's "Humanity and the modern environment". This discusses global environmental change and its impact and considers the role of the geological sciences and the geologist. Sir John presents the alternatives open to mankind in the face of continuing change: adaptation and evolution, control of the environment, or extinction. He concludes that whichever path we take, "our understanding of the past will be central to our ability to survive the future".

Linda Fowler OU Tutor

The Nature of Diamonds by George E. Harlow (ed), 1998, Cambridge University Press, 278pp, £19.95 (paperback) ISBN 0521629357.

This handsome paperback, sporting a cover with an eye-catching picture of the yellow Tiffany Diamond of 128.54 carets cut-weight, was produced to complement an exhibition at the American Museum of Natural History where the Editor, George E. Harlow, is curator of gems and minerals. The thirteen chapters are divided into three sections which roughly cover the Science, the History and Culture, and the Technology related to diamonds. Each chapter has notes and a bibliography, the illustrations are lavish. The book is beautifully presented and contains an amazing amount of information in its 278 pages.

The 12 contributors are experts in their own field and, although they make the subject sing, the style invites study at different levels. Learning is easy because the explanations are so clear and simple without ignoring the complexity. All the technical information is supplied in clever graphics and tables; if you don't want such detail, you can stick to the excellent text. Much pleasure can be gained just dipping into the book and the photographs are outstanding.

Diamond might be the hardest known substance but the mineral possesses other intriguing properties - enough to fill the first 50 pages, not with dry stuff but full of clear explanations of the chemistry and physics of the mineral which hold the attention of beginner and expert alike.

The geology of diamonds is similarly wide ranging; this time, the more fundamental geological information is available on the side, so that if you know these things, you can read the text undistracted by triviality. How the rocks of the mantle and diamonds interact is not something I might have thought about, not in any depth anyway, but it is something to be considered and it is clearly explained. Nor does the text shy away from the complex geochemistry used to differentiate the origins of carbon. There is a short chapter, three pages, on extraterrestrial diamonds, with as many pages of notes and references.

With all that knowledge on board, the history of diamond production is another story. It started in the 18th Century in India, then moved to Brazil and other parts of South America, before South Africa became the major player. More recently, Russia has grown in importance. Diamonds in world trade, national power to match the power and beauty of the gem, the economical aspects of supply and demand; all these are included.

The story, or stories, of eleven great diamonds, those of more than 50 carets, famous for their cut, uniqueness or sheer magnificence as well as their history, are told. After a short piece about cutting diamonds and how that has changed through time, there are chapters about: diamond as jewels, diamond as objects of love, diamonds as regal artifacts, diamonds advertised by Hollywood, diamonds in literature - so you can see how rich the content is. I particularly enjoyed the chapter on coloured diamonds.

The final section could be the most exciting, where diamond is viewed as a strategic mineral. Diamond synthesis and applications are explained and the last few pages contain descriptions of supercomputers, use of diamond in space probes and diamond electronic devices which exploit the high thermal conductivity of the mineral.

The study of diamond joins many disciplines, and the book seems to contain everything you need to know about diamonds, so what more could one ask for, perhaps a few actual samples to play with! The book has been sponsored by the American Museum of Natural History but if you can't get to New York, then the latest displays in London, at the Natural History Museum, will amply suffice. I have already bought a copy of this book and I would recommend you to do so too. It would make a lovely present for anyone.

Jane Randle BA, M.Phil (Open)

1:1 500 000 Magnetic Anomaly Map of Britain, Ireland and adjacent areas, 1998, £4.95 (folded) ISBN 0751829234 ; 1:1 500 000 Gravity Anomaly Map of Britain, Ireland and adjacent areas 1998, £4.95 (folded) ISBN 0751829250; 1:1 500 000 Tectonic Map of Britain, Ireland and adjacent areas. British Geological Survey.

I have been known to be critical of the recent tourist publications of the BGS, considering them shallow, inaccurate and ill designed, although very colourful. These very colourful publications are quite the opposite - they are invaluable. Buy all three and give them prominence when you're considering anything geological and you won't be disappointed. Especially now the price has been reduced from a very unreasonable £25.00 to an affordable £4.95. At the higher price they were out of our league. Now they have been reduced they become very valuable indeed.

All three maps cover the same area, from the Faeroes to France, from the Central Graben to the Slyne Trough, so you can mount them side by side and directly compare geology with tectonics with anomaly across a great deal of the area covered by OU courses.

The data on each map has been garnered from a variety of sources and presented, on the anomaly maps, as colour shaded relief which aids understanding. The tectonic map has, as well as the tectonics, outline geology and the deep seismic reflection profiles (BIRPS, SWAT, WAM etc) are shown. All the platforms, basins and massifs are named. On the anomaly maps it is quite remarkable what is revealed. The magnetic signature of the Tertiary dyke swarms across northern England and Southern Scotland, the dykes of Antrim, the magnetic high of Snowdonia, the low of Cumbria. On the gravity anomaly the Highland Boundary fault stands out, to name but one.

The paper is smooth and takes the ink well - the sharpness is excellent. It is also quite strong - it has to be around me! But be prepared to spend more time on them than you think when you get them out - they're addictive.

Seriously, though - spend the fifteen quid and get them - you won't be disappointed. And hang them up when you're doing any geology and they'll help - lots.

John Colby BA Hons (Open) and
continuing Earth Sciences Student.

Ocean Drilling Program by A Cramp, C J MacLeod, S U Lee & E J W Jones (eds), 1998, The Geological Society, London, 336pp, £69 (hardback) ISBN1862390037.

I didn't sit down and read this book from beginning to end - it isn't that kind of book. There are ten papers on Paleaoceanography and eight on Structural, Tectonic and Sedimentary issues and, naturally, some interested me more than others.

The book starts with brief details of some recent results from the Ocean Drilling Program and then moves through a very wide range of topics, all with the underlying theme of the ODP. Southern Hemisphere Paleaobathymetry; Miocene-Bottom Water Circulation; The Amazon Fan & Heinrich Events; Mud Volcanism in the Mediterranean; Sedimentation Rates on a Mid-Ocean Ridge. Each paper has good, clear, well-labelled diagrams, graphs etc. The text is printed quite small but in a two column format which makes for easy reading. The volume itself is dedicated to the memory of Professor Robert Kidd who was closely involved with both planning and implementing of the Ocean Drilling Program strategy.

Space does not permit a detailed examination of each paper; however, one or two do stand out since they were examining what was, to me, unfamiliar territory. Application of FMS images in the Ocean Drilling Program discusses the rationale, technique and interpretation of microresistivity data collected downhole by four pads fitted to the wireline log. Each pad generates a data-set which can be converted to a false colour image and used to correlate other borehole data and core samples to give a more reliable and comprehensive overview of the three dimensional downhole reality. The combination of FMS (Formation MicroScanner) data and photos of cores was quite striking

I did, however, look at each article and eventually one thing struck me - all eighteen papers are written in the most readable of language for which, presumably, we have to thank the editors. I read, for both pleasure and necessity, a great many technical books and far too many of them are written in PhD-speak, a turgid and mind-breaking form of English which is the literary equivalent of swimming through treacle. Each article in this book entranced me; it was fluid, literate, it sought to enlighten not obfuscate and so, I think this is as near perfection as it could be except for one obvious failing - the price. No matter how enchanting the language or enthralling the topic I cannot possibly afford to buy a book costing £69; 1 imagine even a librarian might balk at such a price.

Jennifer S Holt BSc PGCE Continuing student

Geology of the country around Northallerton by D V Frost, 1998, British Geological Survey, 109pp, £37.50, (paperback) ISBN 0118845357.

The British Geological Survey has a well earned reputation for producing quality material and this is no exception. The first attraction in this (paperback) book is a photograph on the front cover showing the western side of Langdale, a quaternary glacial lake valley, with the Teeside plain beyond. The first of many quality plates, maps, tables and diagrams contained within.

The district described in this memoir lies towards the northern part of the Vale of York; the River Tees and some of its tributaries skirt the northern boundaries. It is covered by the 1:50 000 geological map of England & Wales Sheet 42. Other sources of information are referenced in detail.This is the first comprehensive account of the geology of the area since 1886.

The reader is eased into the area and its geology during the introductory pages and Chapter one. Chapters two, three, four, five and seven describe the geological processes associated with the periods Carboniferous, Permian, Triassic, Jurassic and Quaternary, the resulting strata, mineralisation and topography. The amount of details within each chapter varies enormously. Chapter six is devoted to Structure. Each Chapter contains tables and figures of varying complexity ranging from simple and easily interpreted to the downright confusing (my description).

My particular favourite, having a leaning towards applied geology, was Chapter eight. This outlines the economic geology associated with the area. It sets out the resources, quantities, methods of extraction and associated problems. It confirms that the 'Northerners' have been extracting the proverbial from 'Londoners' for years. To learn more you will have to read the book!

Throughout, there was one slight annoyance and it is a minor criticism; that is, the use of reference names and locations which are not shown on accompanying maps or charts.

I will boldly describe this as a book for everyone with an interest in the geology of Northallerton. As a basic student I found much to keep me occupied. (I am assuming that the more detailed descriptions, maps and charts will mean something to the more experienced). It can be dipped into for reference or it can be read 'cover to cover' like a novel. At £37.50, well worth putting on your birthday/Christmas present list.

Ron Whitfield continuing Earth Science student
and West Midlands Branch Organiser

Mines of Cornwall and Devon; an historic photographic record by Peter Stanier, 1998, Twelveheads Press. 108pp, £l5 (hardback) ISBN 0906294401.

This attractive publication is a companion to the author's Quarries of England and Wales published in 1995. Like that volume, the present title includes many unpublished photographs taken by photographers of the Geological Survey during the period 1903-45.

The closure of South Crofty mine in March 1998 marked a sad day in the long history of Cornish tin mining. This book is therefore a timely reminder of the techniques used in mineral extraction in South West England during the first half of the twentieth century. The historic photographs range in location from the wild Atlantic cliffs of Botallack, with its photogenic engine houses perched on the cliff, to the softer landscapes on the eastern flanks of Dartmoor where minerals were also worked.

In 12 chapters we are given a fascinating insight into the once great industries of the South West based largely on good quality pictures from the photographic collections of the British Geological Survey. Surface and underground mines, mining landscapes, tin mines, small mines, trial surface workings as well as stream workings and tin salvage works are covered. The mines of the Teign Valley, Devon, are also featured.

The techniques, machinery and processes are illustrated and discussed as is the decline of these extractive industries. There are super shots of the industrial landscapes and of groups of miners, some carrying spare candles hung from their jackets, whilst other pictures show men (and women in some of the 1945 shots) at work. The occasional view of a cleaner, better dressed operative is thought to represent the photographer or his assistant. I am sure we have all asked friends and colleagues to feature in our own photographs to act as a scale too!

The roofless engine houses we have all photographed on trips to the area are but ghosts of a rich industrial past and this book brings it to life. In addition, these views are records of great interest to local historians and industrial archaeologists. Most concern tin mining and streaming in Cornwall, although wolfram and iron are also included. Devon is less prominent in the BGS photographic collections but this book features the extraction of barytes, micaceous haematite as well as the Oligocene ball clays in the Bovey Basin.

There is a selected bibliography of books and articles related to the area as well as an index.

Geological excursions to look at the mineralisation in the South West will be greatly enhanced by a reading of this book. It will also provide an appreciation of the importance of the mining industry in the past. I shall eagerly await the next offering by this author to see if the quality of his output is maintained!

Tony Cross, Earth Science Associate
Lecturer, The Open University

CD-ROM Landforms of the Earth by H Frater, 1998, Springer-Verlag, Electronic Media, £24.39, ISBN 3540146105.

Requirements: PC Windows 3.x, Windows '95, (Windows '98?). 486/33 or higher, 4MB RAM (8Mb recommended), soundcard, monitor 640 X 480, 256 colours, double speed CD-ROM drive. Mac: System 7 or higher, 68030/25 or higher, 6Mb RAM (8MB recommended), monitor 640X480, 256 colours, double speed CD-ROM drive.

The advent of multimedia PC systems is having a great impact on Earth Sciences. Landforms, exposures, deposition environments etc. etc. can be drawn together from all over the world and presented for our delectation as we sit huddled over our monitors. This CD-ROM is a fine example of the advantages and some of the disadvantages of this technology.

The CD-ROM is principally concerned with physical geology rather than "hard geology" and I don't propose to criticise the lack of detailed geology content. The main menu shown at the start of the presentation is broken down into the following divisions: "Earth's Major Structures",

Cycles of Change", "Surface Forming Powers", "The Formation of Landscapes" and "Landscapes on Video". There is also a general audio/visual introduction available obtained by simply pressing the "key" marked "video" - not by pressing the button marked "Intro" as in the instructions. The "Intro" key does not exist. There is a "navigator" which allows you to move from one part of the menu to another without constantly pressing the "back" key. There is also a glossary giving definitions of technical terms, as they are required.

There are sub-menus to the above main sections, many of them pictorial. Some of the sections are supplemented with excellent animated line diagrams, as well as a/v presentations.

The impact of such a CD as this is dependent on the quality of the video output of the multimedia system being used. My PC has a 17" monitor and I was distressed to see that the main images were cropped to give a 250 x 200mm main image whilst the line diagrams and the video sequences were presented in a window only 130 x 80mm. The video sequences were annoying to view because of the limited number of pixels. The commentary to the a/v sequences and the general narrative was in English but with such a strange accent that it bordered on the farcical - perhaps not a politically correct comment but it amused most of my family.

I would not buy this CD having viewed it but, despite all its shortcomings, it is an indication of future teaching material. There are good books and bad books and the same will apply to CD-ROM presentations. Sadly this CD falls into the poorer class of material.

Ian W Drummond, BA Hons (Open)
BSc, PhD. (interested amateur)

Destiny or Chance. Our solar system and its place in the cosmos by Stuart Ross Taylor, 1998, Cambridge University Press, 229pp (hardback) £17.95 ISBN 0521481783.

I had to make a great effort to overcome the rather "twee" style adopted by this Australian author. An example: "Jupiter has a single very thin ring. It is made of particles only a micron or so in diameter. Such an ethereal ring reminds one of Tinkerbell, the nearly invisible friend of Peter Pan and Wendy." And another: "The Earth - an island entire of itself", a misappropriation of John Donne's "No man is an island, entire of itself; every man is a piece of the Continent, a part of the main." The author's point is the uniqueness of Earth, whereas Donne's was that we are only a part of the whole.

I was reminded of Arthur Ransome's "Winter Holiday" where the author of Dick's astronomy book was dismissed as "Probably accustomed to lecture to elegant audiences." A connection between astronomy and poetry perhaps?!

However, the effort made and literary spasms ignored, I found this a very readable book, and one which fulfilled the reason for my borrowing it - to supplement knowledge gained from the cosmology sections in S103. It is a good follow-on from Earth Science courses, and probably a pre-read for courses including Planetary Science. A possible failing is a tendency to present debatable points as established facts: "The K/T extinction occurred at a geological instant", and other statements are rather simplistic for anyone who knows a bit about a topic. Taylor presents his (considered) view rather than discussing a subject. However, this is a short book (just over 200 pages) and no doubt his longer "Solar System Evolution: a new perspective", on which this is based, provides more balanced arguments.

However, I don't feel I can overlook his reference to James Lovelock's "Gaia hypothesis that the Earth is alive" without commenting that Lovelock refuted this in his first book on Gaia (almost 20 years ago), and in "The Ages of Gaia" removed all possibly ambiguous references! If one author's work is misrepresented, perhaps one cannot place complete reliance on other interpretations?

Linda Fowler OU Tutor

Encyclopedia of Marine Sciences by H J G Baretta-Bekker, E K Duursma & B R Kuipers (eds), 1998, Springer-Verlag, 357 pages, £l8.50 (paperback) ISBN 3540626751.

From abiotic to zygote, there are 352 pages (plus 5 pages of references) with some 1980 entries in this Second, collected and enlarged Edition, covering the multidisciplinary nature of marine sciences - biology, chemistry, physics and geology. There are also 126 excellent illustrations and extensive cross-referencing. Don't be misled by the word Encyclopedia, this paper-back measures 190mm by 125mm and 15mm thick.

Most of the contributors are from the Netherlands Institute for Sea Research and in the Preface the editors stress that they tried to make the book more than a glossary or a dictionary, especially in the description of marine processes. Some entries have brief definitions or descriptions, as little as one or two lines, while others have up to half a page. In my view the editors' attempt to provide a succinct overview of the major topics in marine science has succeeded. As well as concepts, terminology and methods of the various disciplines, there are 60 extremely interesting historical entries about 19th and 20th century expeditions, including the British Antarctic Expedition (1839-1843), the Challenger Deep Sea Expedition (1872-1876) and the Discovery Expeditions (1901-1903 and 1925-1951).

Although this book is not primarily aimed at students of geology alone, some of the geological entries are very good: for instance, there are several entries relating to sediments with paragraphs on sedimentary structures, sediment classification, sediment drift, sediment gravity flow, sediment transport with an accompanying illustration; there is also a good entry headed "turbidite" which has an excellent illustration of a Bouma sequence and there are entries about plate tectonics and related topics, as well as many others.

At £18.50 this book is perhaps a little expensive for anyone who would only very occasionally dip into it, but it would be a valuable reference book for a teacher or serious student of marine science.

Elizabeth Maddocks, BA (Open)

Chemical Elements in the Environment: Factsheets for the Geochemist and Environmental Scientist by Clemens Reimann & Patrice de Caritat, 1998, Springer-Verlag, 398pp, £64.50 (hardback) ISBN3540636706.

Reviewing books for the OUGS is great fun - laid out are a range of appetising offerings and all that is required is to select one's choice. Consequently I only review those books which interest me. This is a very different situation from that of the professional reviewer who takes what they are given and makes of them what they can. (I was once given three books to review and all three were about walking the Pennine Way - the result was a polemic against the idiocies of the publishing profession.)

I suspect that reading and enjoying this book makes me a "sad person". In which case, fine, I am a sad person. The raisons d'etre behind the volume are the meagre datasets which underlie many of the global figures for background concentrations of the elements and it is truly alarming to discover that "the global norm" may have only one set of readings as its source (or even, heaven help us, an educated guess). The result of a mind boggling amount of compilation is a totally fascinating analysis of everything you ever wanted to know about each element with the limitations of the datasets clearly stated.

The elements are listed alphabetically with four A4 pages for each and for the benefit of S339 students I used Europium as my example (seven years later and I can still discuss Europium anomalies).

Travelling through the numbers of the physico-chemical properties such as atomic number, mass, radius, etc. we come to naturally occurring isotopes and their natural abundance, concentrations in different rocks and typical/possible minerals.

The rest of the first two pages is taken up with values from specific analyses showing median, maxima and minima as well as information

about the substance sampled and where it was collectcd eg.:

- Canadian agricultural soils
- Finnish glacial tills
- Austrian stream sediments

Well alright, I admit that for Europium there is no data for any of these particular sources but the values for Nova Scotia stream water and Norwegian lakes are pretty interesting. Page three gives values for concentrations in precipitation, air, plants and human fluids - definitely the kind of thing I want to know. The last page covers the environmental geochemistry and this could be the most useful of all in many situations. I do want to know that there are insufficient data to assess toxicity rather than the "no evidence" of government statements. This section explores biological impacts, what products we use it for, environmental pathways and mobility together with such aspects as geochemical barriers. Each entry finishes with general remarks which should interest all geochemists and environmentalists, as well as sad people.

At this price I cannot imagine the average OU student buying the book but I can certainly recommend that you borrow it. I found that I wanted to extract some sections wholesale; as a geography teacher I talk about some elements as being essential for plants or toxic to humans but, in many cases, I was not actually sure why "essential" or "toxic" but now I know.

Jennifer S Holt BSc, continuing student

Issues in Environmental Geology: A British Perspective by Matthew Bennett and Peter Doyle (eds) 1998, Geological Society, 438pp, £69.00 (hardback) ISBN 1862390142.

Environmental geology is a combination of geomorphology, economic and engineering geology and is an important and developing aspect of the Earth Sciences (i.e. where the work is). This came across at the Swansea OUGS Symposium in 1998 and this book has very much built on what I learned there. The book is divided into four sections: conservation and management of natural areas; disposal of waste and challenges of engineering geology; mitigation of coastal hazards; provision of geological information and future training needs.

There are nineteen up-to-date case studies which arose from a conference held at the University of Greenwich on the 17th January 1997. Each study includes a number of cross references which those interested could research to broaden their knowledge. The content of the studies cover a huge range which includes arguments promoting the fundamental links between geology, urban development and social history in order to promote public awareness of geology; through to sedimentary processes and the sand environment in the Severn Estuary; and also a study which highlights how platinum group elements which are mined and processed and used by society become concentrated to ore grade in sewage sludge. (Thereby making the sludge into an anthropogenic metal deposit - a resource yet to be harnessed!)

The book is well presented and readable and thought provoking. It is aimed at undergraduate geologists and post graduate environmental researchers as well as local authorities involved in planning, coastal defence and conservation. I enjoyed reading the book but am appalled at the cost of £69 for the 438 paged hardback, the contents of which will soon become out of date due to further research findings.

Sheila Alderman B.A (Open) B.Phil

The Causeway Coast: Exploring the landscape and rocks, 1:50 000 Series, Sheet 7, Geological Survey of Northern Ireland (folded map) 1998, £5.00, ISBN 0751832146.

For anyone interested in how the spectacular scenery of the Causeway Coast in North Antrim was formed, this map is a must. Accompanying the geological map is a series of colour photographs taken along the coast, a well-written synopsis of the geological history of the area and some schematic block-diagrams illustrating how the landscape formed.

The geological map (approximately A2) has been clearly drawn and contains sufficient structural information and annotation to enable the observer to reconstruct the geological relationship between the different sedimentary and igneous units, without distracting from the clarity of the map. As this map is aimed at the non-professional geologist, the associated key has been simplified, listing the rock types against each of the map colours rather than the stratigraphical names. (These can be found on the generalised vertical section.) In addition, the location of fossil-bearing strata is clearly indicated by an ammonite symbol.

The lower half of the sheet contains a generalised vertical and horizontal cross section, a concise description of the geological history of the Causeway coast, and a series of schematic block diagrams illustrating how the landscape formed. The horizontal cross section clearly illustrates the relationship between the conformable basaltic flows and underlying sedimentary units, in contrast to the crosscutting relationship with one of the feeder dykes at Cairrickarade. Although the schematic block diagrams are a good idea, they are rather simplistic and may lead to some minor misunderstandings. For example, the second diagram appears to show tuff and agglomerate forming intrusively rather than extrusively, whilst a description of tile vent and feeder dyke points directly to a conformable basaltic layer. This aside, these diagrams and associated text combine to form a concise and easily understood synopsis of the geological history of the Causeway Coast. The text starts with a brief description of plate tectonics, before describing changes in the palaeoenvironment and mode of formation of the sedimentary and igneous rock units throughout the area's 200Ma history. Clear references are given to each of the nine sites of special interest, with each numerically highlighted at the side of the text, making this an ideal field-guide.

Overall, this map forms a very comprehensive and concise guide to the geological structure and history of the Causeway Coast, North Antrim. It will be of interest to anyone intending to visiting this spectacular region and who wants to know a bit more about how it formed, without being overwhelmed by science.

Dr Arlëne G Hunter PhD, BSc, OU Staff Tutor,
Open University in Ireland

The Geology of the Country around Lancaster by A Brandon, N Aitkenhead, R G Crofts, R A Ellison, D J Evans & N J Riley, 1998, BGS, 181pp, £55.00 (paperback) ISBN0118845268.

This memoir is the first comprehensive account of the geology of the Lancaster district to be published. Comprising some 200 pages of information well augmented by borehole data, maps and diagrams, it covers the period from the early Carboniferous (Dinantian) deposits in the Craven Basin, through the succeeding Namurian sequences up to the Westphalian Lower Coal Measures, a small area of the Permo-Triassic is also included.

The Lancaster district encompasses the major part of the Bowland fells, the Lune valley and the coastal plain bordering Morecambe Bay. The oldest rocks are limestones and shales which were then succeeded by the Namurian millstone grit group which underlie most of the district, comprising a 2.5km thick deposit of deltaic sands, silts and mudstones, providing one of the thickest complete sequences in Western Europe. Deposition continued uninterrupted into the Westphalian forming part of the Lower Coal Measures at lngleton. The Variscan Orogeny tilted, folded and faulted the Carboniferous rocks of the area, further post-Variscan faulting taking place with the onset of the Irish Sea Basin during Permo-Triassic times. With the exception of one tiny area of Permian rock all deposition since this time has been removed, the remaining geomorphology is the legacy of Devensian glaciation resulting in the formation of large drumlin fields, and widespread deposits of till being laid down except in the highest places.

In all, twenty seven rock types are described by way of depositional history, lithology, biostratigraphy and chronostratigraphy. Stratigraphic correlation diagrams based upon borehole information accompanies each

rock type, together with locality maps. Principal structural elements showing the main faulting and folding is discussed at length together with the relevant geophysical and seismic data. Land forms related to glaciation, drainage, drift and post glacial deposition are also covered in detail. Insights into the development of the area as a hydrocarbon resource are afforded by the survey and other industrial minerals mainly for construction are indicated along with potential risk factors such as land slippage and methane seepage.

Overall it is an exceedingly detailed account representing many years of work, it provides a sound base for future research and will be of practical value to those involved in earth sciences and related disciplines. However, at the cost of £55.00 this memoir is obviously much more than a simple geological guide to the area and serious thought will no doubt be given by the individual before purchase.

A Diggles, OUGS, (retired lecturer)

Geology of the country around Stoke on Trent by J G Rees & A A Wilson, 1998, British Geological Survey Memoir 123, 152pp, £50.00 (paperback) ISBN 0118845373.

The area covered by this book is mostly Staffordshire but it does stretch into Cheshire and Shropshire. To the west is the Cheshire Plain mostly covered by Triassic drift whilst the remainder is higher with Triassic drift underlain by Carboniferous rocks, the Potteries with its clay and coal. The book covers the area in age order, starting with a couple of pages on the Pre Carboniferous which has no outcrop in the area and in fact has not even been found in boreholes. The basement is therefore just inferred from geophysical data.

The main chapter (chapter three) is about the Carboniferous, being slightly over one third of the pages in the book. There is very detailed information on the coal measures and each main coal seam with numerous borehole diagrams. The upper sandstone units are then described.

There are no Permian outcrops but faulting of this age continued into the Triassic. Sandstones and conglomerates of the Triassic are each described in detail mostly illustrated by logs from quarries and one borehole correlation diagram. The Cheshire basin deposits are concealed under the glacial and much of the information was obtained from boreholes to investigate salt subsidence.

The Palaeogene (chapter six) describes the intrusive dykes and provides a map showing where these outcrops are. Chapter seven describes the Quaternary which blanket covers much of the area. Chapter eight is structures Pre-Variscan, Variscan and Post-Variscan, mostly faulting and a brief description of basin formation.

Chapter nine, Applied Geology, very briefly touches on the economic geology - coal, clay, ironstone, sand and gravels, salt, metal, oil and gas, considering the importance they have in the area. Even briefer reference is made to "made ground" which covers large areas of the district including domestic and industrial waste and the waste from extraction of coal, iron, clay etc. Followed by two pages on hydrogeology and three on hazards, a topic covered very superficially and considered by the BGS to be outside the brief of this book.

There is of course a very complete list of references at the back of the book which can be obtained from the BGS library. One question I have for the BGS is when is someone going to make a supplement which lists the places where the outcrops can be viewed, possibly coupled with accessibility and where to gain permission for visits. To sum up, the book is a useful reference for the area BUT at £50 it is just too expensive for most people to buy.

Wendy Hamilton BSc, BA Hons (Open)

The Development, Evolution and Petroleum Geology of the Wessex Basin by Underhill J R (ed), 1998, Geological Society, London, Special Publications, 133, 429pp (hardback) £79 ISBN 1897799993.

The papers contained in this book are written by and for professional petroleum geologists, as a result of a conference at the Geological Society held in 1995. The volume will not therefore be easily understood by undergraduate students of the Open University. However, if you are familiar with Dorset, and the Jurassic sediments, it will be worth the effort. To read and reread all the papers will give you an understanding of the underlying structure of the Wessex Basin, which includes Hampshire, the Isle of Wight and part of the Channel where oil exploration has been conducted over the past 50 years.

The book is divided into sections on hydrocarbon habitat, stratigraphic syntheses, regional studies, structural studies, sedimentological advances, petroleum geochemistry and oil field case histories. The information for each paper is the result of years of research on surface outcrops as well as the seismic and borehole exploration for oil. The data have been used to reconstruct the fault movements that occurred during the Mesozoic and Tertiary. Movements which buried Lower Lias clays deeply enough to 'cook' the oil and allow it to migrate into the reservoir rocks of the Sherwood Sandstone and Bridport Sands were reversed in the late Cretaceous and Tertiary. In spite of extensive exploration oil has only been discovered at Wytch Farm and Wareham, with a small field at Kimmeridge. Many of the papers attempt to explain why only the Wytch Farm fault block still contains oil, the Kimmeridge field being something of a mystery.

In the introduction Underhill sets the scene by defining the Wessex Basin and outlining its stratigraphic framework. 50 years of oil exploration focused initially on anticlinal structures onshore, offshore exploration commencing in 1963. More recently exploration has concentrated on fault-related traps and the Wytch Farm reservoir was first discovered in 1973. [The announcement on Boxing Day was greeted with an enormous cheer in my kitchen, from where we could see the drilling rig.]

Fault movements, erosion, subsidence and sedimentation are discussed by many of the authors. Together, the papers illustrate the infinite number of variables in depositional environments. In the Triassic and Jurassic the north Atlantic was opening, causing rifts where slices of the continental crust were slipping downwards as they moved apart. Then later, in the movement known as Alpine, these slices were squashed together again and pushed upwards. The study of both the sedimentary rocks and their fossils includes a paper on microfossils, and one on palynology.

The detailed information given by each author can be open to different interpretations, a fact which is acknowledged in their conclusions. However, the full picture becomes clearer as each new line of enquiry is followed. It is a pity that the proof reading is occasionally somewhat slapdash, leaving grammatical and spelling errors as well as the transposition of words and phrases which make nonsense of the text.

In general, I would not recommend this for undergraduates, but for those who have studied the Jurassic and Dorset in particular since graduating it should prove enlightening.

Jo Thomas BA Hons (Open)

Coastal Defence and Earth Science Conservation by J Hooke (ed), 1998, Geological Society, 270pp, £59.00 (hardback) ISBN 1897799969.

This book is the result of a conference held in Portsmouth which focused on these issues. Three members of the Dorset GA Group attended the conference as, at the time, we were heavily involved with the sea defences at Ringstead Bay in Dorset. Attitudes to such tactics have changed since then and hopefully are moving towards our original viewpoint. This book reflects that change from "stop the erosion at all cost" to "let's look at alternatives and consequences overall". It also outlines the tremendous difficulties in collating all concerns in the subject of coastal protection in particular and conservation in general.

The contents cover frameworks for conservation and defence, methods and techniques, strategies and decision making, resources and evaluation. It also has the case studies concentrated on at the conference which were Poole and Christchurch Bays, so the book is of particular interest to

Dorset geologists. Locations as far flung as Cornwall and Scotland, via the Isle of Wight, Somerset and Norfolk, for instance, also are used as examples of good and bad policies.

It is a 'must have' sort of book for anybody interested in geology and conservation as it gives all aspects of the problems involved. There are, of course, plenty of people who are interested, and vociferously, in preservation of the coasts at all costs. This book does help explain why their needs have to be met as well as that of those who would prefer to 'let it all go'. The price, of course, is a drawback but if you can afford it buy it; if you can't afford it, persuade your local museum/library to add it to their stock.

Doreen Smith BSc and continuing Earth Science student

Environmental Interactions of Clays - Clays and the Environment by A Parker & J E Rae (eds),1998, Springer-Verlag, 271pp, £49.00 (hardback) ISBN 3540587381.

Clay minerals are common in the surface layers of the Earth and their physical and chemical properties allow them to be extensively exploited in the modern world. This book is about some of those properties, why the properties are important, and how they are assayed and tested.

'Clays and the Environment' was not my first choice of a book to review and it was with some trepidation that I began reading it. The book contains 7 review articles covering a spectrum of subjects from the environmentally practical (Clay Barriers in Landfills), to the more esoteric (Interactions of Non-Volatile Micro-organic Pollutants and Clay Minerals in Surficial Environments).

From an Earth Science point of view, there is much to propagate one's interests in new directions, although a geological background is not necessary in order to appreciate most of the articles. The contents include quite a lot of physical chemistry, and I would have understood more if I had a better grounding in that discipline, yet there is much in the book that does not assume this knowledge. It really does depend on what particular aspect of clay interactions with the environment takes your interest.

For example, being a medic, I found the article on Clay Minerals and Health comfortably free from physical chemistry: the discussion largely concerned the structure of studies designed to show the effects on health of exposure to the various minerals. This chapter provides a nice introduction to environmental medicine, almost from first principles.

The articles are well written and there is a consistency of style which is often not found where there are many contributors to a collection. All the reviews are well supported by references (20 pages of references follow one chapter!). If there is any criticism I have of the book, it is the variable quality of illustrations: some are beautiful coloured graphs; most are clear and concise, but some have been reproduced very poorly (I suspect from old lecture material), often with tolerance bars blurring into data points. With the graphing and illustrative software available today, there really can be no excuse for poor diagrams in a publication of this sort.

Notwithstanding, the book is interesting and stimulating. It is well put together, consistent in quality of writing and ease of reading, and it would be useful to anyone whose main interest is in geology, or in the environmental sciences. Like S330 it was daunting at the outset but also, like Oceanography, rewarding in its mixture of disciplines.

Dr Vivian Stevens, BA Hons (Open)

Our Cosmic Origins by A Delsemme, 1998, Cambridge University Press, 322pp, £16.95 (hardback) ISBN 0521620384.

This book gives a very readable account of the path to the building blocks for life on earth, and perhaps elsewhere in the universe, charted from the Big Bang through our evolution to the highest known intelligence. Such a journey is highly complex requiring an inter disciplinary approach and careful structure if it is to achieve the author's stated aim of keeping it simple whilst not leaving any significant gaps in our knowledge. I think he succeeds admirably, from the first chapter which includes a step review of the scale of the universe from the infinitely large to the extremely small, which the reader can choose to skip over, to the last which invites exploration of questions of "where do we go from here". In between we have the formation of stars and planets and the important role of asteroids and comets in bringing water, gasses and carbon compounds to our fledgling planet, leading to the emergence and evolution of life. Throughout he draws on what is known from the science of cosmology, physics, astronomy, geology, chemistry, palaeontology, biochemistry and biology, expounding hypotheses that may yet fill some of the gaps, but guarding against personal bias. The material is bang up to date and would complement many OU science courses as further reading. However, it is a fascinating account in its own right, for me made more readable by the appendices, containing some of the technicalities I might have stumbled on in the main body of the text. There is also an extensive glossary and bibliography.

Though £17 may be hard on some pockets, I would recommend it as an addition to any reference library.

George Raggett BA Interested amateur

Geology of the district around Newcastle upon Tyne, Gateshead and Consett. Memoir for 1:50000 Geological Sheet 20 (England & Wales) by D A C Mills and D W Holliday, 1998, British Geological Survey, 148pp, £50.00 (paperback) ISBN 0118845381

A memoir, according to the Oxford English Reference Dictionary, is "an essay on a learned subject specially studied by the writer" or, in this case, writers who have or still are working for the British Geological Survey. Not only is this an excellent reference document for those who are interested in geology but it also gives an insight into the industrial history of the Newcastle district.

The memoir is laden with excellent graphics, some in colour. The majority of the memoir is taken up with the coal measures, Upper Carboniferous, and the mass of borehole/mine data in stratigraphic columns showing the correlation of the numerous coal seams throughout the district.

Although the Upper Carboniferous takes up the majority of the memoir other features are not dismissed. The memoir begins after the introduction with section 2, which describes the underlying structure, Lower Carboniferous (Dinantian). Section 3 details the Upper Carboniferous, see above. Section 4 describes the faults and fold structures known within the district. Section 5 briefly describes the igneous rocks, mainly the Whin Sill. Section 6 describes the Quaternary glacial and post glacial deposits and section 7 briefly describes the economic geology of the area. The appendices cover the boreholes of the area and two cross sections showing the geology of two sections of the tunnel built for the Kielder Water scheme.

In retrospect I should have had a copy of the 1:50000 Geological Sheet 20 (Newcastle upon Tyne) open while reading the memoir, for the two documents are inseparable. Perhaps the memoir should include a copy of the relevant geological sheet. Overall an excellent production providing an absorbing read, well worth borrowing from a library.

Mike Anderson BA (Hons) Open

Beyond El Niño: decadal and interdecadal climate variability by Antonio Navarra (ed.), 1999, Springer-Verlag, 374 pp., £65.00 (hardback) ISBN 3540636625.

This book was written by many of the world's current leading authors and researchers into climate change. It presents an overview of research into, as well as the modelling of, shorter-term climatic change over periods between about 10 and 100 years. Despite the main title, it is not really a text on El Niño, but on all the areas of climate change related to changes that can be observed, in particular, within the tropical oceans. Publication was as a part of the European Commission's Environment and Climate research programme, which includes support for DICE, the "Decadal and Interdecadal Climate variability Experiment".

To some extent, the text develops concepts discussed in the OU Oceanography course (S330), but it is not a specific aid to the part of the course which deals with the El Niño variation. As the subtitle indicates, this book is more about atmospheric climate change and its modelling than about changes within the oceans. The articles go into a great deal of detail within their specific topics and even revealed some new areas for research that I had not heard of, as a meteorologist! The most important link between the oceans and the world's climates is revealed by many of the articles; for example, the possible link of El Niño and the Southern Oscillation (ENSO) to cycles in the temperate climates (such as our own). For instance, there are subtle variations of the atmosphere and ocean in the North Atlantic region (the North Atlantic Oscillation), possibly linked to El Niño, which change the seasonal weather types affecting the British Isles.

It becomes clear to the reader, however, that interdecadal climatic variations are not necessarily linked to the century-scale global-scale climatic warming that is a major concern of scientists, politicians and public alike. Indeed, there are many feedback loops within the shorter-scale climatic changes linked to phenomena like El Niño. Many of these feedback loops are negative and make these shorter-term changes cyclic. Over the medium term, the changes induced in the atmosphere by the changes in the ocean often themselves bring about a return of the ocean to its former state.

There are clearly many uncertainties about the proposed interactions of the ocean and atmosphere presented in this book. Most are due to shorter-term (weekly to monthly) variability of weather systems, as well as the unique character of each weather system day-by-day.

It would be of use to know at least some higher-level mathematical physics if the reader is to understand the methods of research being used by the authors. It would also help the reader to have some knowledge of numerical (computed) methods of prediction and the significance of certain levels within the atmosphere (e.g. 500hPa: the level of non-divergence at about 1500m altitude). However, although the importance of empirical orthogonal functions (EOFs) becomes evident within the text, there are not too many complex mathematical formulae to grapple with! Many authors like to display their mathematical prowess, even though this can make the text heavy-going. In these cases, it is probably best to read the Introduction and jump to the Conclusion after trying to make sense of the diagrams!

Unfortunately, some of the figures in the book are poorly reproduced - a great pity in these days of scanners and software designed specifically to improve reproduction within textbooks at low cost. However, perhaps the most disappointing aspect of the book is the poor editing, which allows the inclusion of some almost indecipherable "English" by a few of the authors. This error may, in part, be due to the choice of Antonio Navarra as the volume's editor. Although he is a highly respected climatologist, it quickly becomes evident from the Preface that his English is poor and he received little, if any, help from a sub-editor.

This book is quite a weighty tome and is unlikely to be suitable for, say, bed-time reading by the casual amateur interested in learning a bit more about El Niño. However, it will be of use if you wish to know in detail about climatic changes on small time-scales, bringing together many strands of climate research in different parts of the globe. Each chapter deals with a different topic or aspect of research into a particular topic and is well laid-out.

Jim Galvin, BSc Hons. (Open)

World Mineral Statistics 1992-96: production; exports; imports, by L E Stockwell *et al*., 1998, BGS, 296pp, £80.00 (paperback) ISBN 0852723083.

I have to confess that I picked this up thinking that there might be some useful material in it that could be used for S268 tutorials! It's one of the annual series, and consists of tables of minerals that are traded, showing imports, exports and production.

It's a reference book, not a bedtime read; but some fascinating material here - for example, the UK production of Fuller's Earth falls from 1992-95 and then rises again; the UK exports of it follow the same pattern, whilst the amount imported increases 10 fold between 1992-94 and then falls back to less than a quarter of the 1992 value. Hmm - no jokes about cat-litter!

At the back are some very useful maps showing world production of some commodities, followed by some graphs. Fascinating stuff, at £50 clearly a reference library tome!

Jenny Bennet

Earth: Evolution of a Habitable World by Jonathan I Lunine, 1999, Cambridge University Press, 319 pages, £19.95 (paperback) ISBN 0521644232.

The author is Professor of Planetary Sciences at the University of Arizona and his book covers not only the geological history of Earth but also man's place in it.

The book is divided into four parts: Parts One and Two deal with the scale of the universe, scientific notation, the constitution of matter, forces and energy, fusion, fission and the formation of elements, the uses of isotopes, geologic time and an introduction to plate tectonics. These two parts contain the basic concepts of physics, chemistry and geology needed for an understanding of what follows. In the Preface Professor Lunine urges readers to dip into those chapters which deal with unfamiliar material. The content of these early chapters would be very familiar to anyone who has studied the Science Foundation Course.

The eleven chapters of Part Three cover the chronological history of the Earth from the formation of the Solar System up to "the Age of Humankind". In Part Four "The Once and Future Planet" the author looks at climate change over the past 100,000 years and then considers human induced global warming and the problems of an expanding population and Earth's limited resources.

The book is well illustrated with black and white diagrams, maps, graphs, etc, and there are eight colour plates, including some Hubble Space Telescope images. At the end of each chapter there are questions for consideration plus recommended reading. For anyone who has read second level Earth Science courses this book is easy to read but it should also appeal to non-science students who are interested in the Earth on which they live.

Elizabeth Maddocks, BA (Open)

Physics of the Space Environment by Tamas I. Gombosi, 1999, Cambridge University Press, Atmospheric and Space Science Series, 339pp, £45.00 (hardback) ISBN 052159264X.

It may not be too poetic a metaphor to liken our Earth, on an interplanetary view, to an ocean liner cruising inexorably through the currents and whirlpools of local not-so-empty space, its ionospheric superstructure buffeted by the gusts and storms while down below decks, where we live, all is mostly serene. Once in a while, the routine fluctuations signalled by the aurorae are dwarfed by an outburst so wild that we temporarily lose parts of our civilisation's electrical networks of power and communication. (There must also be induced electric currents in the oceans and solid earth?) The variation in the cosmic drizzle of energetic particles, the root mechanism of carbon-14 activity, is another indicator of the interplanetary climate.

Just as the meteorologist has tried to capture the atmospheric phenomena with differential and vector algebra, so in the past half-century the physicist of the space environment has sought to untangle the observations of space 'weather' as a set of plasma, electromagnetic, and thermodynamic phenomena, driven primarily by that same power source, the Sun, but chiefly via the emission of particles from the million-degree boiling of the corona.

Gombosi is a former Soviet space worker, latterly working in the NASA Venus programme. The main text of his book has three parts;

I - Theoretical Description, a comprehensive mathematical coverage of the relevant physics, II - The Upper Atmosphere, and III - Sun-Earth Connection which, after a chapter on solar physics, covers aspects of the interaction between the solar emissions and the Earth's environment. Appendices provide a compact and comprehensive reference source on the algebra and physical quantities and there are problems (no answers!) at the end of each chapter.

For me, the wealth of complex equations which occupy Part I and many pages of Parts II and III generate admiration rather than enlightenment. However, this book is no mere exercise in applicable theory. The latter parts are well illustrated with diagrams and concise but lucid descriptions of the observational and model data, including pointers to those aspects which are still problematic. The coverage demonstrates why research in these topics forms such an excellent grounding in contemporary physics.

The serious student of interplanetary and near-Earth physics at advanced undergraduate and postgraduate level should find this book well worth assessment, both for study and reference. Parts II and III could be well worth library browsing for the student who wishes to get a feel for the current problems and issues in Sun-Earth interactions, perhaps to guide a personal choice for subsequent research.

George Sudbury PhD (space astrophysics),
CEng and ES student.

Seven Wonders of the Cosmos by J V Narlikar, 1999, Cambridge University Press, 324pp, £12.95 (paperback) ISBN 0521638984.

Professor Narlikar, an astrophysicst and former student of Fred Hoyle at Cambridge, has been awarded the UNESCO prize for science popularisation. In "Seven Wonders of the Cosmos" he aims to provide an insight into the current state of understanding of the features of the Universe in as non-technical form as possible. In this he succeeds - provided you have some scientific background, especially a grasp of basic physics, for which S102 is quite adequate.

The seven wonders of the title are not single objects but subject areas which move outwards from the Earth to the furthest reaches of the visible Universe. He starts simply by explaining how the Sun can rise in the west and why the sky is blue, yet the Earth remains stationary in a dark sky when viewed from the illuminated surface of the Moon. His second wonder is the evolution of stars as he deals with the physical characteristics of stars, using our own Sun as an example. Here, as throughout the book, he gives an historical perspective so the reader sees how theories have developed as scientific skills and knowledge have grown. Having explained how red giants and white dwarfs are believed to evolve he moves onto exploding stars, describing how supernovas, neutron stars, pulsars and star birth are all inextricably linked.

In the second half of the book he turns to the general and special theories of relativity which I confess to only skimming through. This did not seem to detract from my understanding of the importance of gravity for quasars, active galaxies, black holes and singularities. The sixth wonder, looking at the illusions in space caused by gravitational lensing, where all is not where it seems to be, precedes the large scale structure of the Universe. The Big Bang, redshifts and Hubble's law together with the elusive dark matter lead onto postulation about its - and our - eventual fate. He concludes with a list of some of the mysteries still waiting to be solved.

This is a very readable book, full of everyday analogies to help explain quite complex phenomena. The chapters are divided and sub-divided which, together with a comprehensive index, keep the subject under control. It is full of well-captioned illustrations, graphs, diagrams and photographs which add to the interest and help with understanding. Unfortunately they are not in colour which would enhance many of them but presumably that would make the book more expensive. Anyone who has an interest in astronomy, and those who watch Patrick Moore's "Sky at Night", will find it answers many questions. It would make a good introduction to S281 for which it would be a useful general companion. I enjoyed reading it, finishing with an increased awareness of the wonder that "scientific laws discovered over three centuries on this tiny planet apply to a history of billions of years of a vast universe".

Jenny Flake continuing Earth Science student

Review of Stone: Building stone, rock fill and armourstone in construction by M R Smith (ed), 1999, Geological Society, London, Engineering Geology Special Publications, 16, 478pp, £89 (hardback) ISBN 1862390290.

The book is a report of a working party of the Engineering Group of the Geological Society consisting of geologists, civil engineers and architects. It is a reference work in which each specialism may learn from the others and will be invaluable to minerals planning authorities as well as to any amateurs who are interested in the quarrying and use of stone at the present day. Unfortunately the price probably puts it beyond the reach of amateurs, or even the local authorities. Why is it that the professional geological community take the trouble to produce excellent information, of great value to so many others, and then price it out of the market?

The chapter headings will give a taste of what you're missing. Introduction - stone; production statistics; a future for building stone. Geology - stratigraphy; structural geology; weathering; geomorphology; main rock divisions; igneous, sedimentary and metamorphic as building stones. Exploration. Assessment of suitability and resources. Extraction. Processing. Rock fill. Armourstone. Stone for buildings and civil engineering. Stone repair and restoration. The work concludes with details of test methods, and stone and rock properties particularly of British building stones. Each subject is dealt with in great detail and, though more technical than an amateur would need, it is written in such a way that the specialists in one discipline are spared the jargon of the others. Good plain English is always the best way to exchange information.

This book deserves to find its way around the OUGS membership and return to the library at length with many names on its borrowers list.

Jo Thomas

Holiday Geology Guide: Mining in West Cornwall. ISBN 0852723067; Holiday Geology Map: North York Moors,ISBN 0852723059, A3 three-fold publications from BGS Earthwise - £1.95 each.

"Mining in West Cornwall" looks at the reasons for the mining industry's existence, at its history and at the remaining evidence. It digresses into sociology with some discussion of mining life and finishes off with details of some of the more interesting remains that can be seen. These are keyed into a small-scale satellite image map of the area, overprinted with some of the relevant geology. Unfortunately neither directions, nor a grid reference, are given. Whilst this is an interesting overview, I feel that for anyone with more than a very casual interest it may meet with severe competition. There are some excellent local publications such as J.A. Buckley's "The Cornish Mining Industry", or Peter Stanier's "Cornwall's Geological Heritage" (both 48 pp), which cost very little more (under £3 when I last looked) but contain a wealth of interesting detail, plus reading lists.

"North York Moors" includes an A3 satellite image of the area, again overprinted with the geology. I found the 3-D shading difficult: valleys looked like ridges until I followed their instructions and turned the map upside down! The reverse of the sheet includes some illustrations from Richard Bell's excellent "Yorkshire Rock – a Journey through time", another Earthwise publication, with brief descriptions. It is unfortunate that the Whitby Jet, which was a reasonably blackish sort of colour in the original, has come out a pale greyish-green! Once again, this is really just a taster: "Yorkshire Rock", although 3 times the price, contains maybe 9 times as much material and represents better value for money.

Compared with some of the earlier "Holiday Geology Guides" I found both of these disappointing. These two seem to be at a more basic standard and lack much of the detail and sign-posting that would help a visitor to find out more in the short time available on holiday.

Linda M H Fowler

Holiday Geology / Discovering Geology, Earthwise Publications, BGS. A series of publications from the BGS, all priced at £l.95. Three-fold A3 size and laminated. As several of the series are urban geology (good for studying when the field sites are muddy!) the lamination could be useful on a wet day. The four reviewed here are part of a growing series of Geology Guide cards

Trafalgar Square, by Eric Robinson & Martin Litherland, 1996: An aerial view of the Square and its surrounding buildings, including a cut-away of the rocks beneath. Above ground it is easy to follow with short paragraphs of information arrowed to the respective site. The buildings and street furniture are named and dated, and the building stones used identified. Vehicles are used for scale. Below ground things were not so easy to follow, shading is used in the rock layers rather than keeping a constant colour, this resulted in confusion over the underground starting out in the London clay but suddenly disappearing into the chalk. The reverse side of the map gives interesting information into why the local rocks have not been used for building, along with a potted palaeogeological history of the Square. A useful little guide for the beginner, a pleasant half-day could be spent looking about. But one thing puzzles me - does the pedestrian subway at Whitehall really go right down into the chalk, well below the underground system ?

Nottingham, by Graham Lott & John Cobbing, 1996: Another urban geology guide but completely different to the above. A small map of Nottingham City centre is provided, with the sites of interest colour coded. Each colour a geological period of time, e.g. for Carboniferous read green. Around the map are good colour photographs of the noteworthy buildings along with a geological and economic history of them. Now if you know Nottingham you will be able to put each building in its place on the map, but if not you will have to work out which period its building stone comes from, find its corresponding colour (of which there can be several of that colour) and then find it on the map. Probably the best approach is to match a street name with map then look for buildings afterwards. The reverse of the map has useful information including how to recognise sandstones and limestones, how they formed and why they are a particular colour. It is rather confusing to start with, trying to match photos to map sites, but once you've found your bearings another pleasant half-day is in prospect.

Isle of Wight, by Ramues Gallois, 1996: A 3-D geomorphological map of the island, where each surface rock type is colour coded. It is informative in terms of what type of landscape each strata produces and in what type of land/seascape the rock formed. The reverse of the map describes the rock types and where to find them. Rather nice to see this novel approach to geology and perhaps it will catch the eye of some, but it is assuming some basic knowledge, such as recognition of the rock types as well as ammonites.

Fossil Focus: Ostracods, by Ian Wilkinson, 1996: An interesting account of these tiny crustaceans both past and present. It includes their evolutionary history (with a colour coded geological time chart matched to illustrations of what was around), their morphology, and where to find them today. All clearly illustrated and easy to follow. I certainly know more about them now. Useful and informative, but I don't think I would pay £l.95 for this laminated guide when there is nowhere to take it.

Glynis Sanderson BSc Hons (Open) PG Dib LIS

Holiday Geology Guide - The Tower, by Eric Robinson and Martin Litherland, 1999, Earthwise Publications, £1.95, A3 folded, ISBN 0852723326.

This guide folds out to reveal an aerial view of the area - the Tower of London, Tower Bridge, and a section of London Wall. It is cut away to reveal the rocks underneath. Red numbers clearly identify the features to look out for, and information on these surrounds the illustration. The geology seems fairly comprehensive: firstly the origin of the underlying strata, from the Cretaceous chalk, through the London Clay to the glacial sands and gravels, then onto the history of the buildings and pavements themselves, from Roman Londinium, through William the Conqueror to date. The source of each building stone is identified. Which are the oldest rocks in the Tower? The diamonds in the Crown Jewels - cut from the Cullinan diamond, which is dated at 3 billion years. And another interesting snippet - Lady Jane Grey was executed here at Tower Green. The Block itself is surrounded by black basalt paving cubes, and pale Mountsorrel granite setts from Leicestershire, where Lady Jane Grey had a home.

Greenwich, by Eric Robinson and Martin Litherland, 1999, Earthwise Publications, £l.95,A3 folded, ISBN 085272327X. The Greenwich guide, like the one to the Tower, has a geological timescale and detailed photographs of some of the rocks.

Not all the rocks here are as genuine as they look. For example the tall columns within the Royal Naval College Chapel are not Siena Marble with green serpentine bases, but painted onto papier mache! Don't worry, though, there are real rocks aplenty. For example the floor of the Painted Hall is made of white Italian Carrara Marble, a blue-grey marble crowded with freshwater snail fossils (either from Sussex or Kent) a black crinoidal limestone from Belgium and a grey-green squid-filled limestone from Sweden).

I really liked these cards. They are great value, beautifully illustrated and informative. There is something here for everyone - snippets of information for children and experienced geologists. If you are going to London to visit the Tower or the Royal Observatory or Maritime Museum, arm yourself with these leaflets.

Sue Russell BSc Hons (Open), PGCE

Sedimentology & Stratigraphy by Gary Nicholls, 1999, Blackwell Science Limited, 355pp, £26.50 (paperback) ISBN 0632035781.

Sedimentology & Stratigraphy has been written as an introduction to sedimentology and stratigraphy for those beginning their geological studies at University. A quote from the preface states "It is hoped that the text is accessible to those completely new to the subject but at the same time covers the technical jargon and terminology used in more advanced work." It is an easy book to pick up, look something up and put down again. It has a clear layout and numerous references to relevant sections in other sections of the text. At the end of each subject chapter is a list of further reading on the subject. I found the book to be an excellent revision text reminding me of quite a few things I had misplaced in my memory. Not a few times did I nod off while reading the book during commuting to and from work, in my mind an excellent goal for a textbook. The subject is well presented with clear and concise drawings tables charts and photographs to illustrate the subject where necessary. As a text book and reference document I found it excellent, it is not a book to read cover to cover, refer to previous paragraph. A good buy for a beginner in geology.

Mike Anderson BA(Hons) Open

Holiday Geology Guide: Isle of Wight by Ramues Gallois, 1999, BGS, A3 folded, £1.95, ISBN 0852723245.

This is an excellent companion to the Holiday Geology Map; Isle of Wight published in 1996. A geological map and stratigraphic log, connected by colours, inform both the amateur and the not-so-amateur about the horizons and their exposure localities. Colour photographs of the contrasting coastlines at Shanklin, Alum Bay and Whitecliffe Bay and Bembridge Ledges whet the apatite and stimulate the desire to explore. The excellent explanatory text is informative, concise and easy to read and understand. A block disgram illustrates the environments130Ma, 90Ma, 50Ma and 30Ma: from the dinosaurs, through sea and swamp conditions to uplift during the Alpine Orogeny. An interesting view of the chalk cliffs, taken from the Needles has the dip superimposed showing the fold axis. A well- written pocket guide ("pocket" being a misnomer) and well worth the £1.95.

Jane Clarke MPhil (Open) BA Hons (Open)

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South East: Yvonne Cutt
South West: Linda Fowler
Walton Hall: Jenny Bennett
Wessex: George Raggett
West Midlands: Ron Whitfield

West Scotland: Stuart Fairley
Yorkshire: Jenny Jennings

Co-opted officers (non-voting)
Covenants: Ann Goundry
Journal Editor: Jane Clarke

Past Presidents of the OUGS

1973-4	Prof Ian Gass	1983-4	Prof Geoff Brown	1993-4	Dr Dave Rothery
1975-6	Dr Chris Wilson	1985-6	Dr Peter Skelton	1995-6	Dr Nigel Harris
1977-8	Mr John Wright	1987-8	Mr Eric Skipsey	1997-8	Dr Dee Edwards
1979-80	Dr Richard Thorpe	1989-90	Dr Sandy Smith	1999-	Dr Peter Sheldon
1981-2	Dr Dennis Jackson	1991-2	Dr David Williams		